

# Review of the CERN-SPS QGP Search and Open Questions

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(\*late substitute)

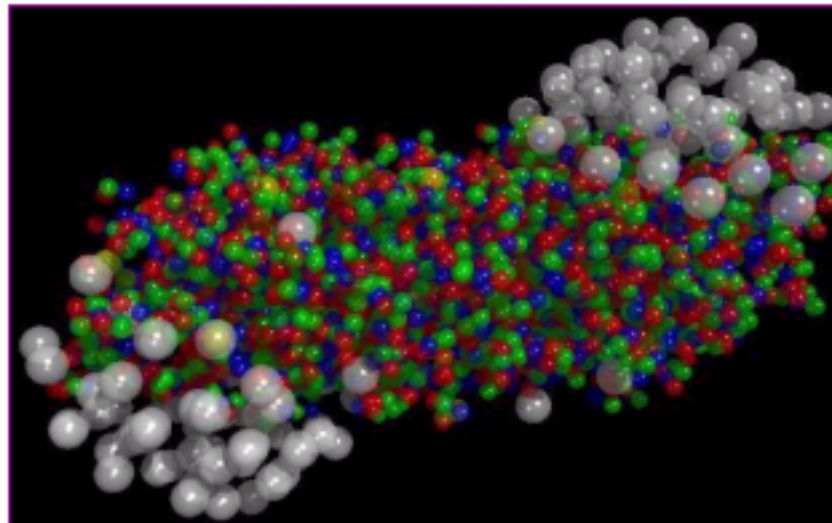
# CERN Press Release

<http://press.web.cern.ch/Press/Release00/PR01.00EQuarkGluonMatter.html>



Organisation Européenne pour la Recherche Nucléaire  
European Organization for Nuclear Research

## New State of Matter created at CERN

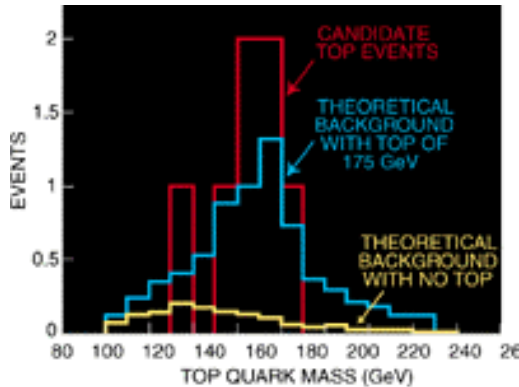


At a special seminar on 10 February, spokespersons from the experiments on [CERN](#)'s Heavy Ion programme presented compelling evidence for the existence of a new state of matter in which quarks, instead of being bound up into more complex particles such as protons and neutrons, are liberated to roam freely.

Theory predicts that this state must have existed at about 10 microseconds after the Big Bang, before the formation of matter as we know it today, but until now it had not been confirmed experimentally. Our understanding of how the universe was created, which was previously unverified theory for any point in time before the formation of ordinary atomic nuclei, about three minutes after the Big Bang, has with these results now been experimentally tested back to a point only a few microseconds after the Big Bang.

# Top Quark Standard

March 2, 1995



“Both CDF and D0 report a probability of less than one in 500,000 that their top quark candidates could be explained by background alone.”

Followed by simultaneous publication in Physical Review Letters and accompanying detailed articles for review.

- It is unrealistic to expect a statement like “**there is a probability of less than one in 500,000 that these data are explained by non-plasma models alone.**”
- However, the same level of scrutiny is expected given the scientific importance.
- There is no scientific paper on the CERN conclusions. Thus I will use the presentation of U. Heinz (co-author with M. Jacob of the press statement) as a guide.



# Advance Warning !



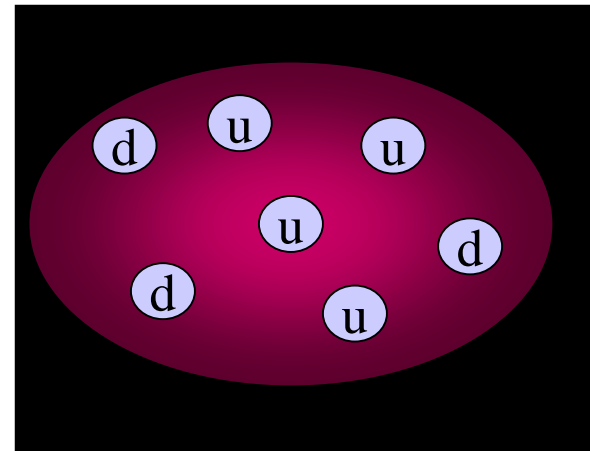
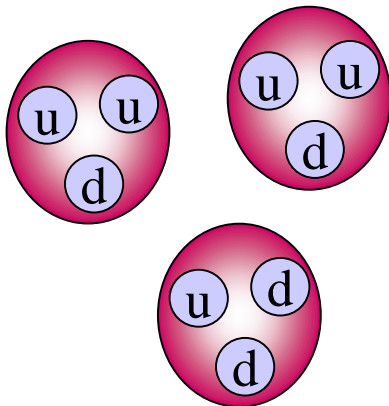
I have worked on AGS experiments E878, E864, E941 and now work on the PHENIX experiment at RHIC.

**I will give a critical analysis of the CERN-SPS results and press release.**

**The opinions expressed here are my own and others in the field may disagree.**

# Confinement

- Normally quarks are bound together (confined) in hadrons
- There are no observations of free individual quarks
- However, QCD predicts that at high density (5 to 10  $\rho_0$ ) and high temperature ( $\sim 150$ -200 MeV  $\sim 10^{12}$  °F), the quarks are no longer confined, but rather are “asymptotically free” and form a **plasma of quarks and gluons**

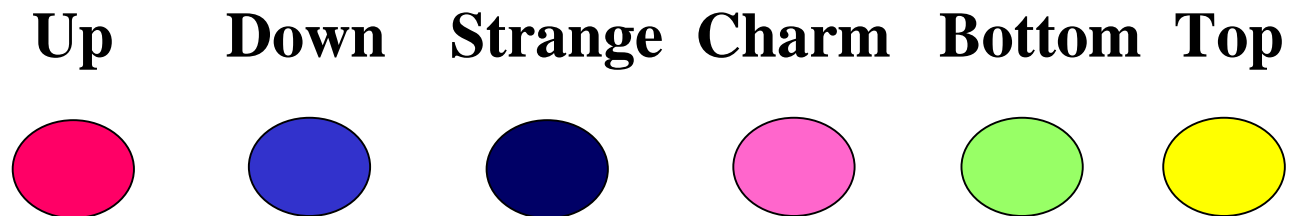


# Chiral Symmetry

If the individual nucleons disappear, and the system is a plasma of individual quarks and gluons, one expects that the quarks will act as nearly massless objects.

This transition to nearly massless quarks is called the restoration of approximate **Chiral Symmetry**.

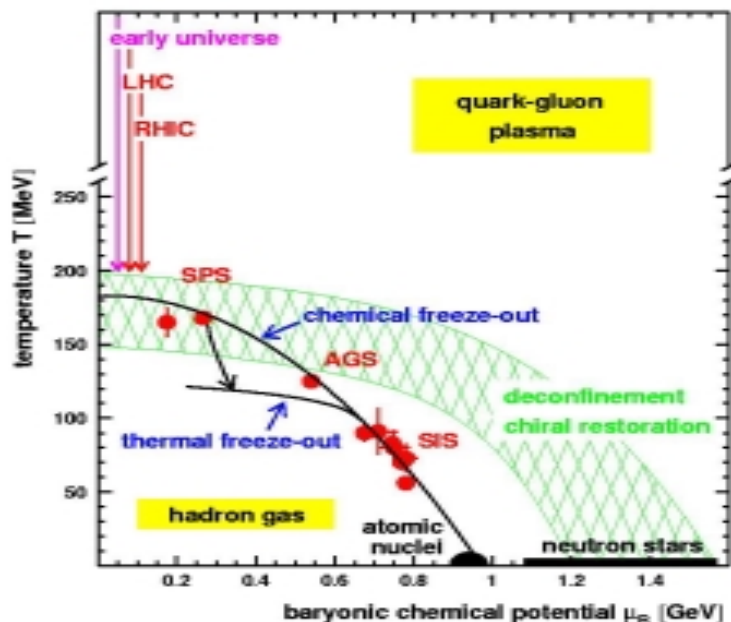
The up and down quark are expected to have masses of  $\sim 5$  MeV, while the strange quark is reduced to a mass of  $\sim 150$  MeV.



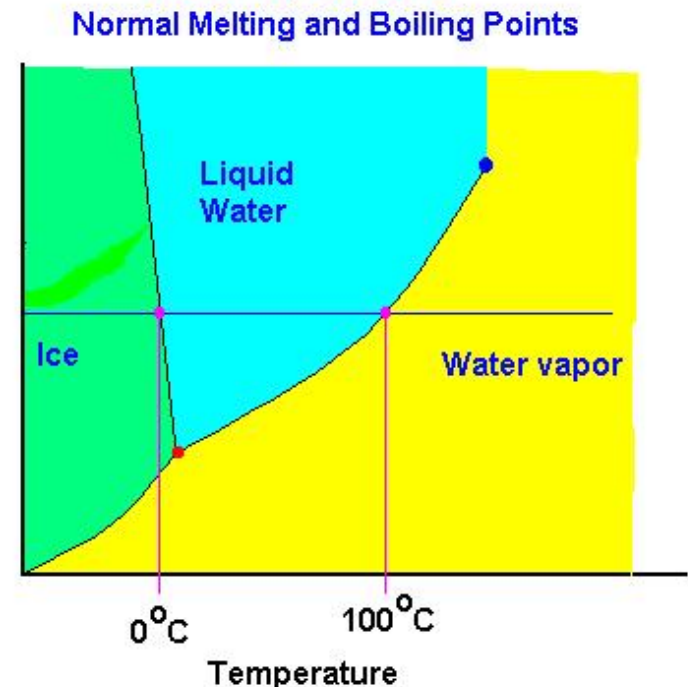
# Phases of Matter

We would like to understand the phases of nuclear matter, just like we understand the phases and phase transitions of water.

Although lattice QCD gives us a theoretical guide, the figure on the left is more schematic.



760 mm

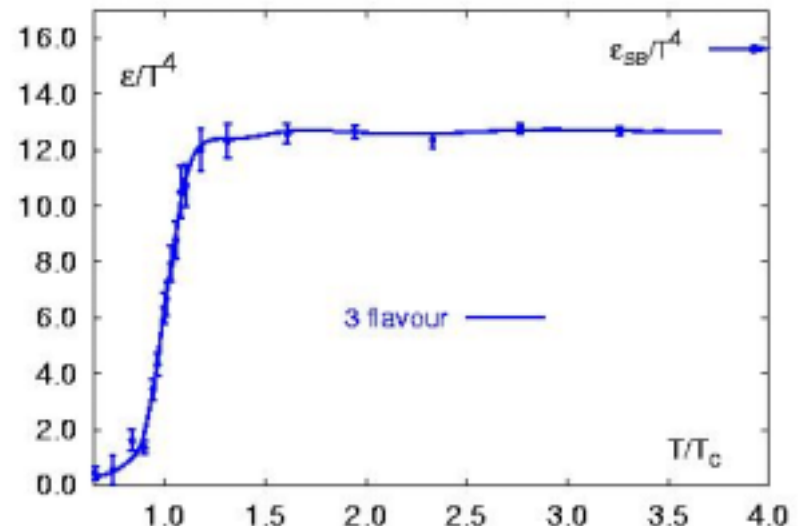


# Lattice QCD

Indication of phase transition to deconfined matter.

Transition energy scale is of order  $\sim 0.6 \text{ GeV/fm}^3$   
or  $T_C \sim 170 \text{ MeV}$  at zero net baryon density.

Also, there are some questions about the exact energy scale.



(F. Karsch, hep-lat/9909006)

(Karsch, Laermann, Peikert, 99')

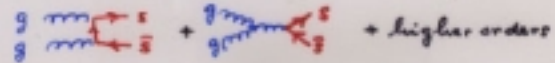


# Key Points

- The evidence for this new state of matter is based on a multitude of different observations.
- Many hadronic observables show a strong nonlinear dependence on the number of nucleons which participate in the collision.
- Models based on hadronic interaction mechanisms have consistently failed to simultaneously explain the wealth of accumulated data.
- On the other hand, the data exhibit many of the predicted signatures for a quark-gluon plasma.
- Even if a full characterization of the initial collision stage is presently not yet possible, the data provide strong evidence that it consists of deconfined quarks and gluons.

## Key QGP predictions:

- ✓ Strangeness enhancement and chemical equilibration due to shorter time scale for  $s\bar{s}$  production: (Rafelski + Müller '82)



↔ gluon deconfinement + chiral symmetry restoration  
(high gluon density + low mass thresholds)

Hadronic background: associated production + strangeness exchange

Multi-strange (anti) baryon production inhibited by low densities and high mass thresholds in hadron gas.

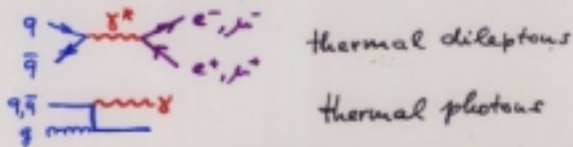
- ✓  $J/\psi$ ,  $\chi_c$ ,  $\psi'$  suppression due to color screening (Satz + Matsui '86)

↔ color deconfinement + high gluon density

Hadronic background: hadronic FSI with incoming nucleons and comoving produced hadrons

Comover scattering unable to reproduce observed  $\psi'$ ,  $\chi_c$ ,  $J/\psi$  suppression pattern.

- ? Thermal electromagnetic radiation: (Shuryak, Kajantie, Ruvshenkov...)



backgrounds: Drell-Yan,  $D \rightarrow K\pi \rightarrow \mu^+\mu^-$ , bremsstrahlung from charged hadrons;  $\pi^0, \eta, \dots \rightarrow \gamma\gamma$

Marginal S/B @ SPS, but more hope at RHIC and LHC (thermal rate  $\sim T^4$ )

## Strangeness Enhancement

## $J/\psi$ Suppression

## Thermal Radiation

# Strangeness Enhancement

**“A particularly striking aspect of this apparent ‘chemical equilibrium’ at the quark-hadron transition temperature is the observed enhancement, relative to proton-induced collisions, of hadrons containing strange quark.**

**Lead-lead collisions are thus qualitatively different from a superposition of independent nucleon-nucleon collisions. That the relative enhancement is found to increase with the strange quark content of the produced hadrons contradicts predictions from hadronic rescattering models where secondary production of multi-strange (anti)baryons is hindered by high mass thresholds and low cross sections.**

**Since the hadron abundances appear to be frozen in at the point of hadron formation, this enhancement signals a new and faster strangeness-producing process before or during hadronization, involving intense rescattering among quarks and gluons.”**

# Mechanisms

## Quark-Gluon Plasma

- gluon fusion:  $gg \rightarrow s\bar{s}$
- current quark mass:  
 $m_s = 150\text{MeV}$
- threshold:  
 $E_{\text{th}} = 2m_s \approx 300\text{MeV}$
- equilibration time:  
 $\tau = 3 - 6 \text{ fm}/c$

Contents of strange quarks relative to non-strange quarks in QGP is greatly enhanced compare with HG

## Hadron Gas

- hadron scattering:  
 $NN \rightarrow KYN, \quad MN \rightarrow KY$   
 $MM \rightarrow K\bar{K}$
- constituent quark mass:  
 $m_s = 450\text{MeV}$
- threshold:  
 $E_{\text{th}} > 700\text{MeV}$
- equilibration time:  
 $\tau = 10 - 100 \text{ fm}/c$
- pion rescattering and resonance:  $\pi\Delta(1232) \rightarrow K\Lambda$

# Strangeness enhancement & chemical equilibration

- (1) Hadron yields compatible with chemical equilibrium at

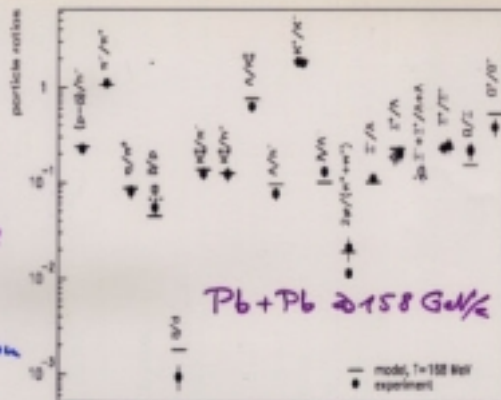
$$T_{chem} = 168 \text{ MeV} \approx T_{had}$$

"pre-established chemical equilibrium"



statistical hadronization of quarks & gluons

(U.H., QM97; R. Stock, PLB456, 271)



Braun-Huenger, Hepp, Stachel, PLB465 (99) 45

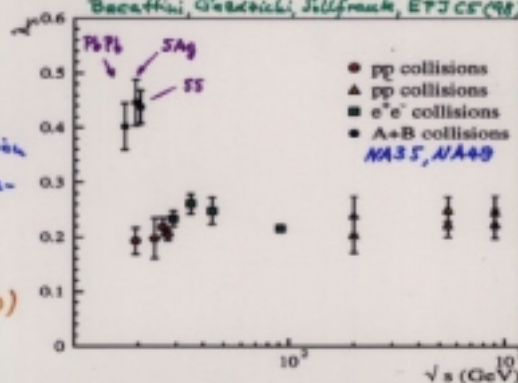
Beattini, Giacchi, Sillfrank, EPJ C5 (98) 463

- (2) Global strangeness enhancement by factor 2



rapid strangeness production before or during hadronization

(Rafelski + Mueller, '82; Ewings et al., Friman, Knoll et al., '88-'90)

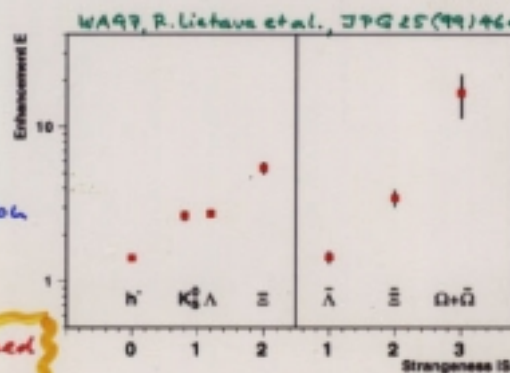


- (3) Large specific enhancement factors at  $\sqrt{s}_{cm}$  (PbPb vs. pPb) for multi-strange hadrons



statistical hadronization

(Rafelski '94, Bialas '98)



(1)-(3) cannot be explained by hadronic FSI!

Hadron abundances are consistent with chemical equilibrium at a temperature of  $\sim 170$  MeV.

Overall strangeness production is enhanced relative to  $e^+e^-$  and  $p+p$  collisions.

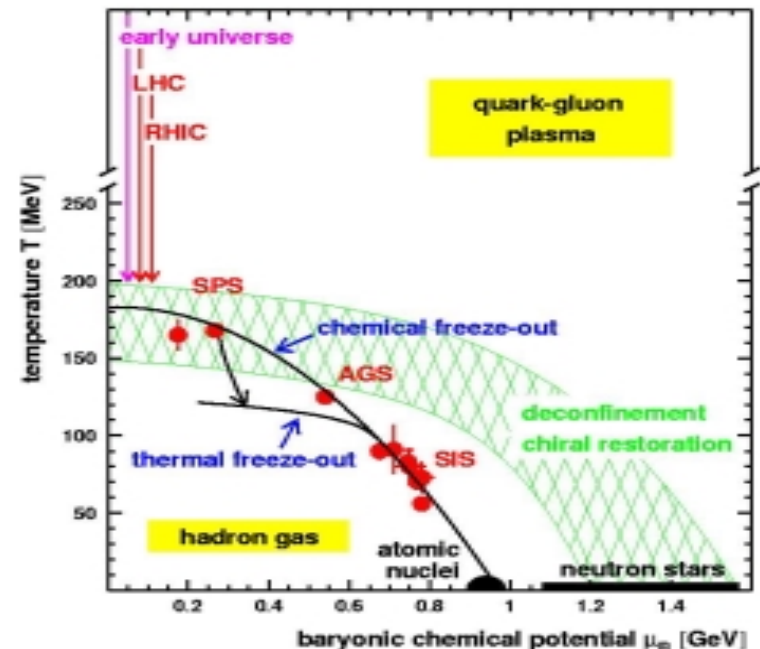
Multiply strange baryons and antibaryons show even greater enhancement relative to a scaling of  $p+p$  by the number of participating nucleons.

# Not just Pb-Pb....

“Experimentally [strangeness enhancement] is found not only in lead-lead collisions, but even in sulfur-nucleus collisions. This is consistent with estimates of the initial energy densities above the critical value of  $1 \text{ GeV}/\text{fm}^3$  even in those collisions.”

**Thus the phase transition occurs around  $1 \text{ GeV}/\text{fm}^3$  corresponding to a temperature of 170-180 MeV.**

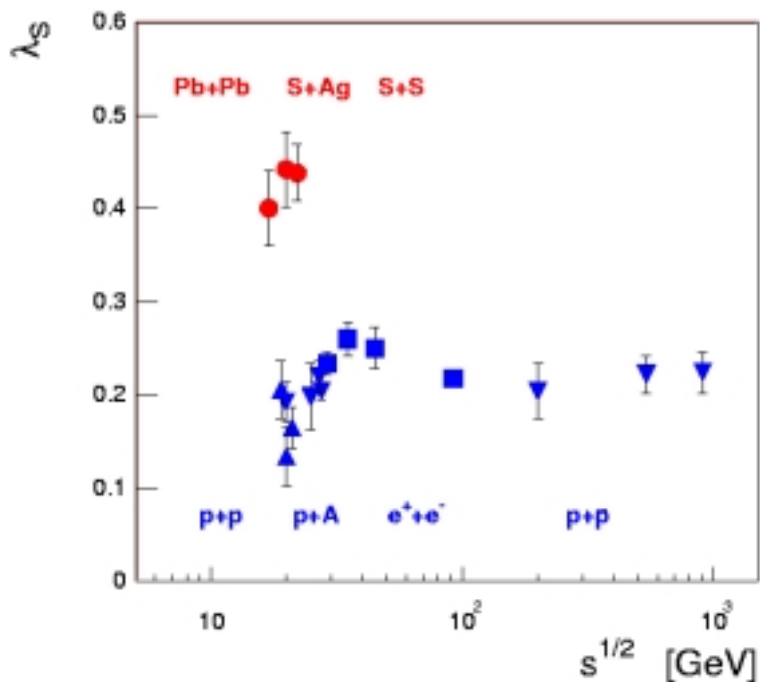
**This pushes the lattice QCD result into the SPS region at non-zero baryon density.**



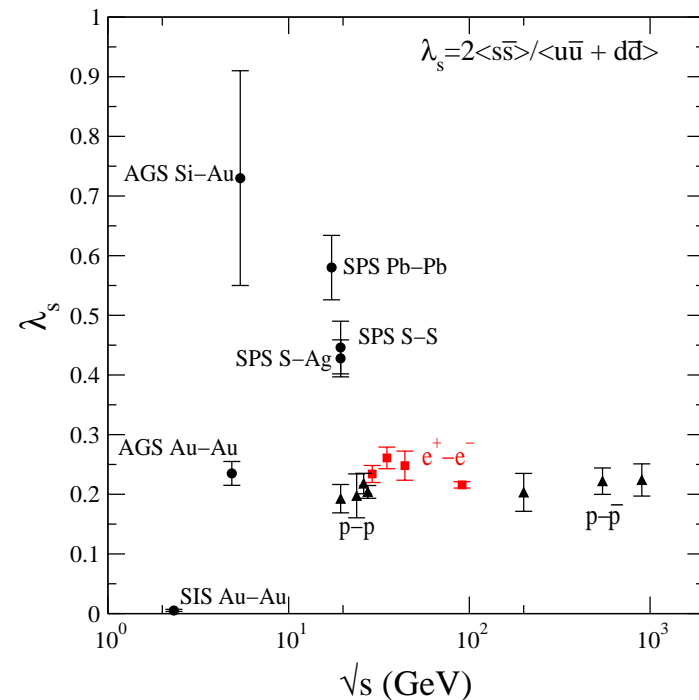
# Lower Energies

$$\lambda_s = \frac{\langle s\bar{s} \rangle}{\langle u\bar{u} + d\bar{d} \rangle}$$

$\lambda_s$   
K-  
st  
lo



F. Becattini et al., EPJ C5 (1998) 143



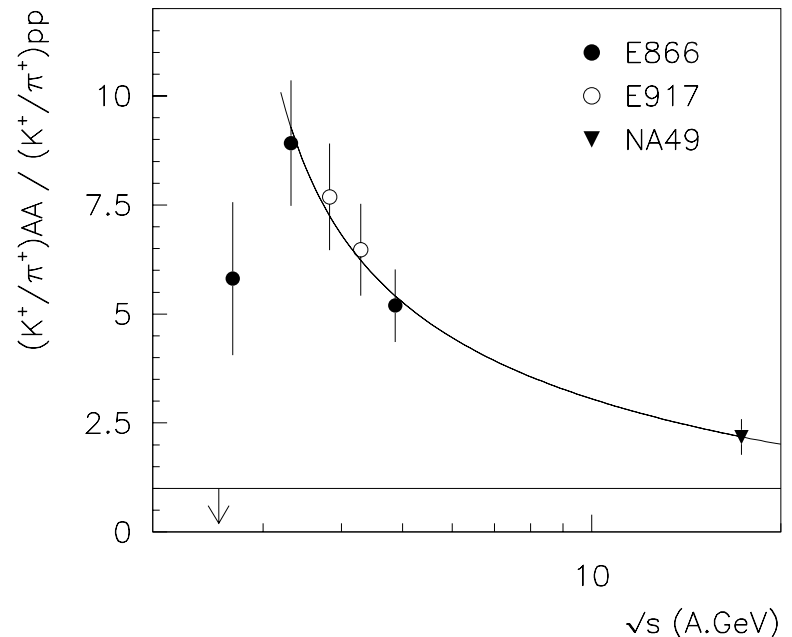
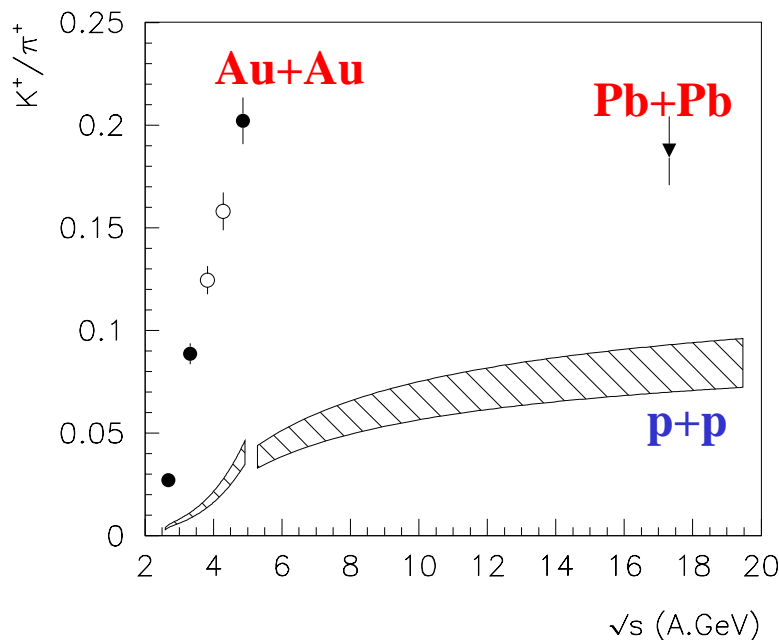
F. Becattini et al., reference.....



# Where is the phase transition?

Excellent data from E917 shows that strangeness enhancement is observed in Au + Au collisions down to threshold.

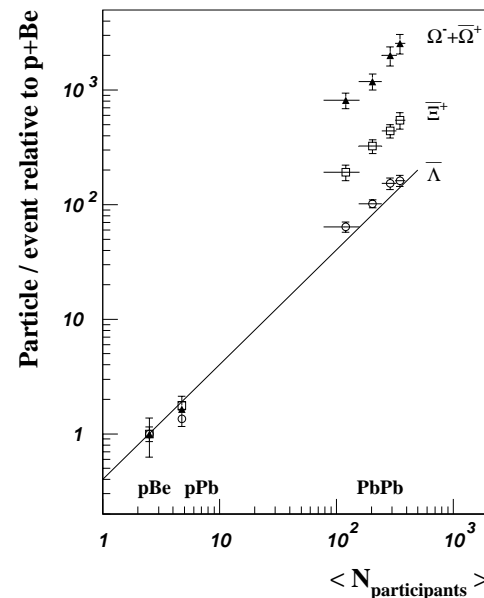
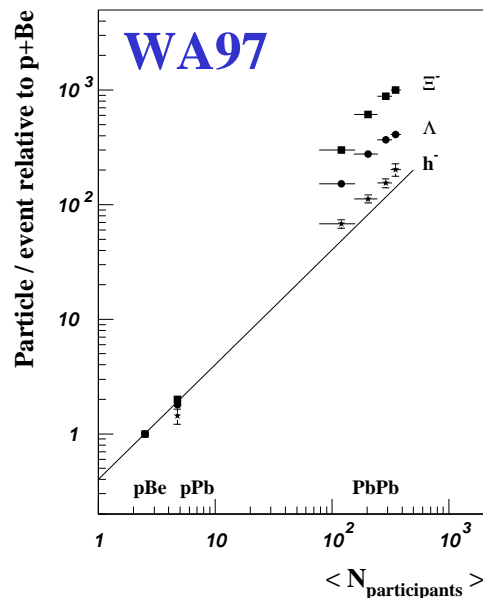
Is this a different mechanism? Is the phase transition at AGS or even BEVELAC energies? What are the assumptions?





# Multiply Strange (Anti) Baryons

“The multi-strange particle yields are proportional to  $N_{\text{part}}$  as would be expected if strange quarks are equilibrated in a deconfined and chirally symmetric quark gluon plasma.”

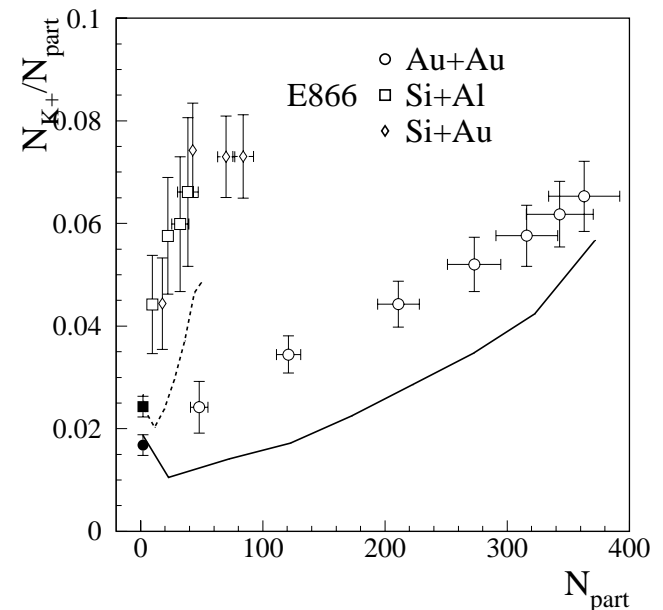


# Intriguing Result

The large yields of  $\Xi$  and  $\Omega$  are difficult to explain with traditional hadronic rescattering due to low cross sections.

Need to investigate other ideas (eg. Junctions / Junction loops)

However, note that scaling with  $N_{\text{part}}$  is violated in many ways in A+A collisions as well as p + A. Thus  $N_{\text{part}}$  scaling is not a good baseline.

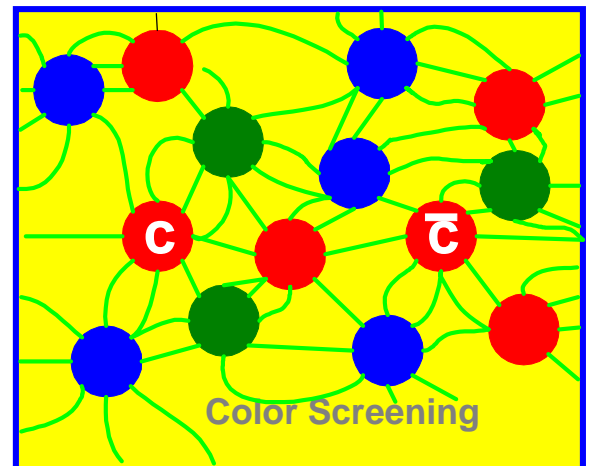
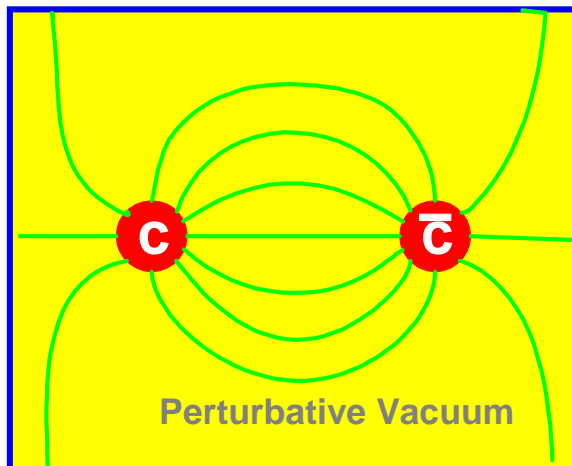
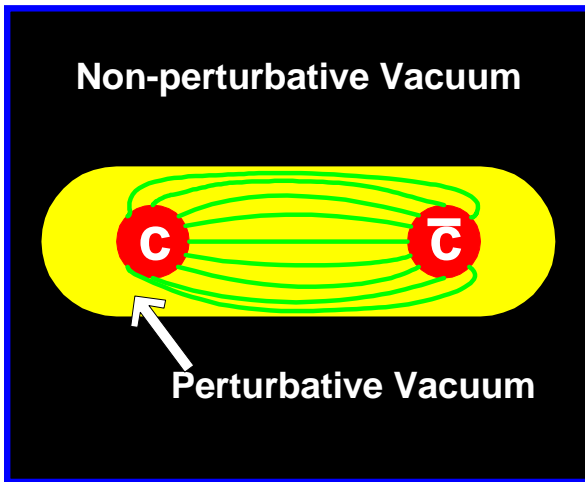


# J/ψ Suppression

## Vector meson J/ψ

– bound state of a charm quark and anti-charm quark

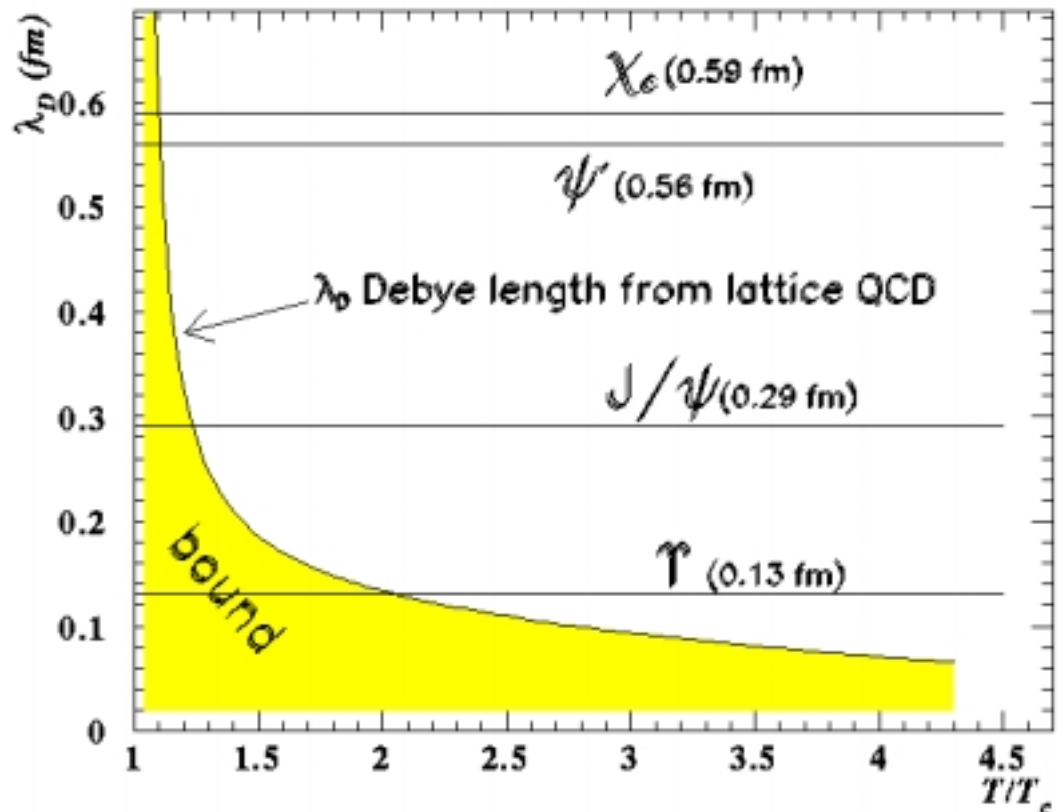
The pair feels an attractive force and can form the above bound state. However, in the middle of a quark-gluon plasma the attractive force is screened.



# QCD Thermometer

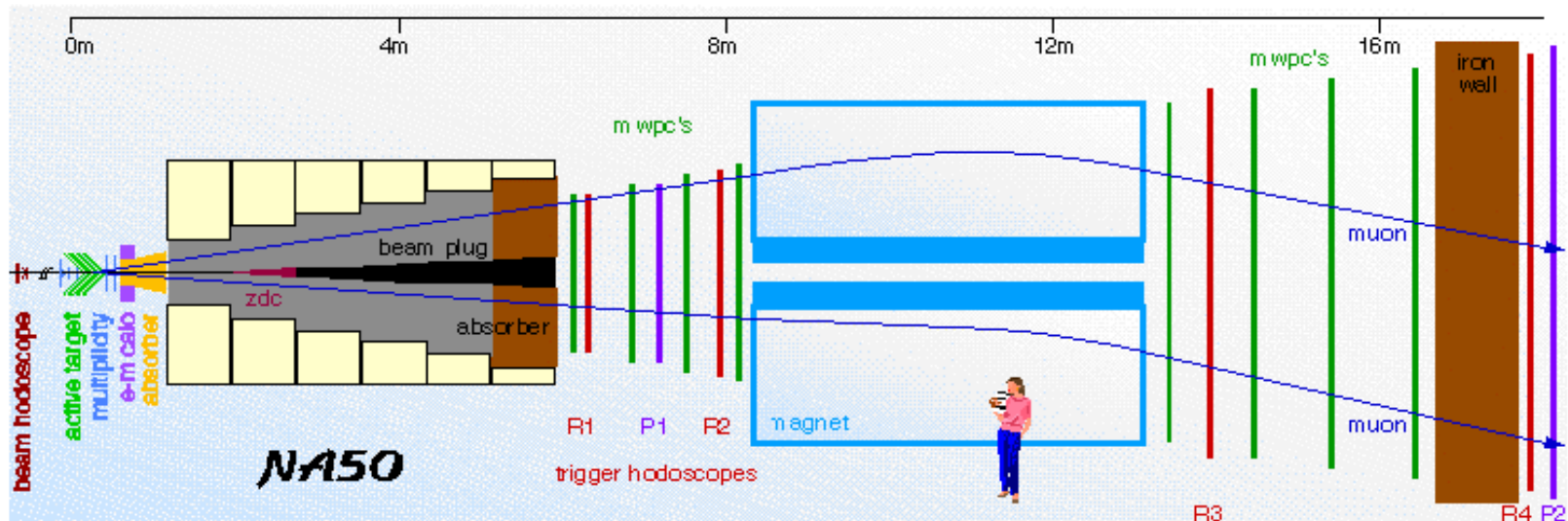
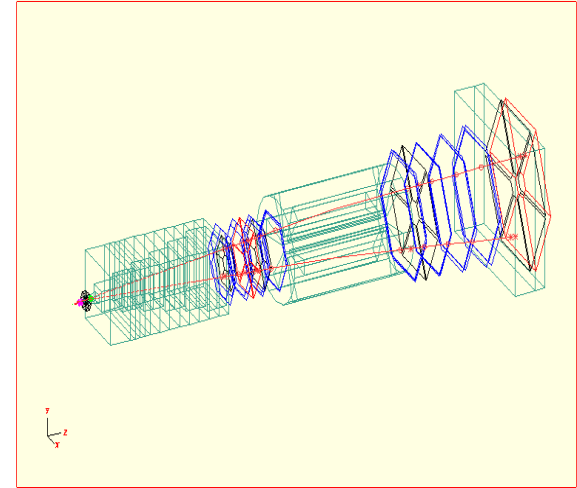
Hadrons with radii greater than  $\sim \lambda_D$  will be dissolved (suppressed)  
Debye screening length  $\lambda_D \sim 0.5$  fm at a temperature  $T = 200$  MeV

As the temperature is raised above the critical temperature, one should see the sequential suppression of the various “onium” states



# NA50 Spectrometer

- Excellent muon identification
- Triggering using hodoscopes
- High flux of incident beam  
 $\sim 5 \times 10^7$  ions / spill
- Large Data Sample  
 $\sim 2 \times 10^5$  J/ $\psi$



# NA50 Pictures

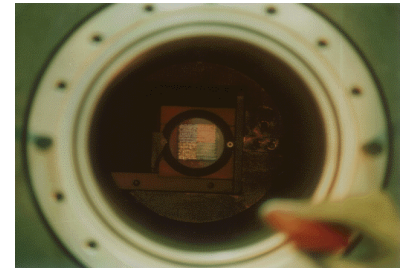
Muon Spectrometer



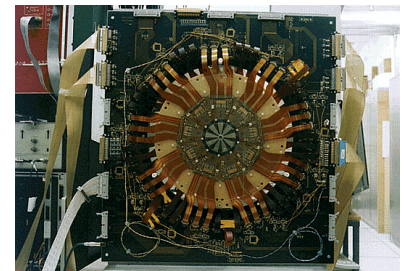
Active Target



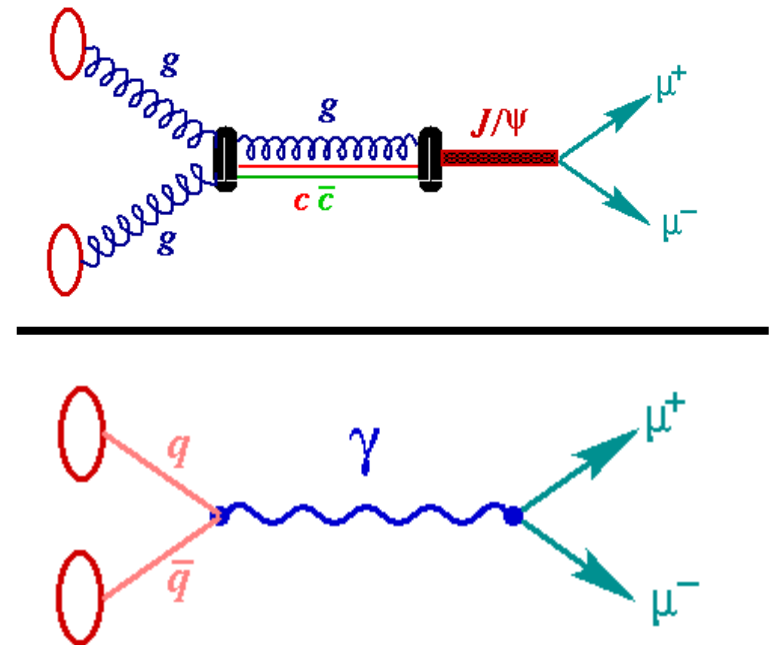
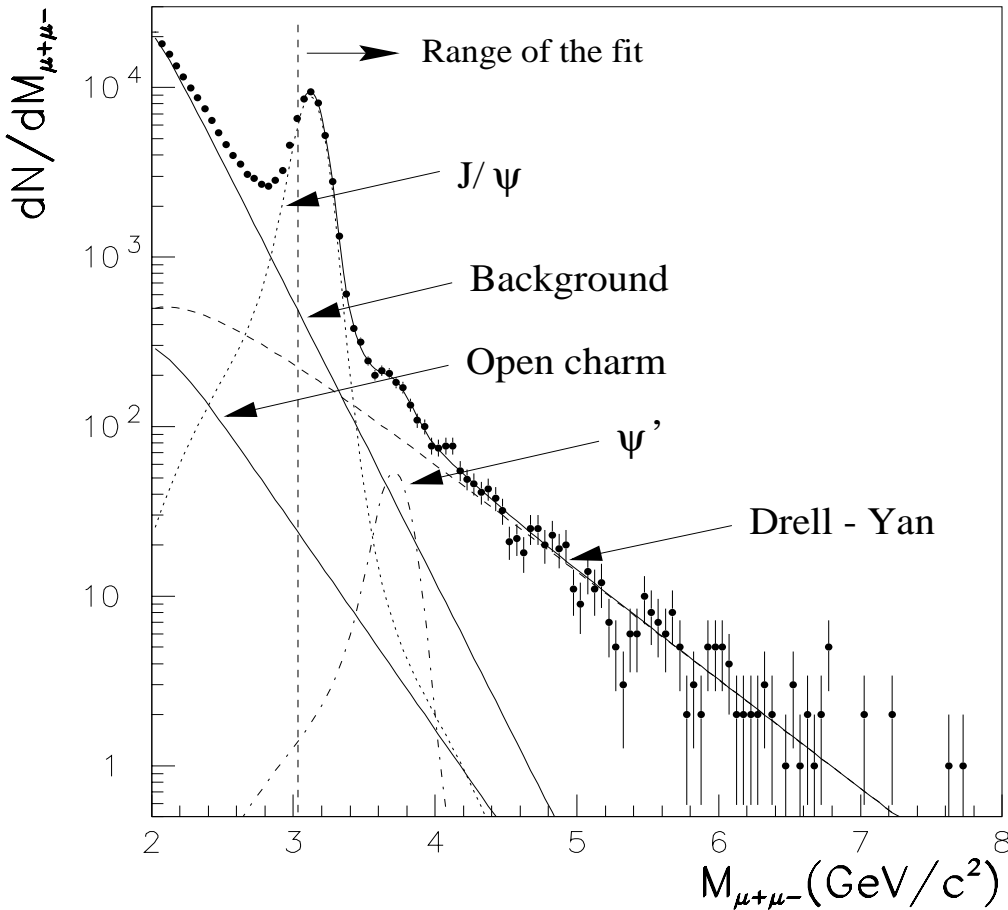
Zero Degree Calorimeter



Multiplicity Detector



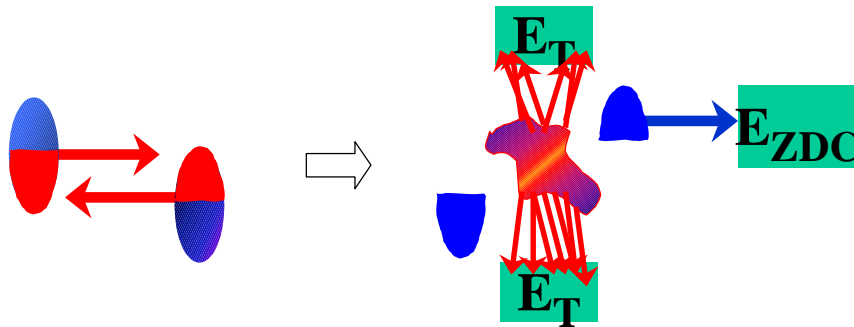
# NA 50 Dimuon Mass Spectra



Drell-Yan process is unaffected by nuclear medium (standard candle)

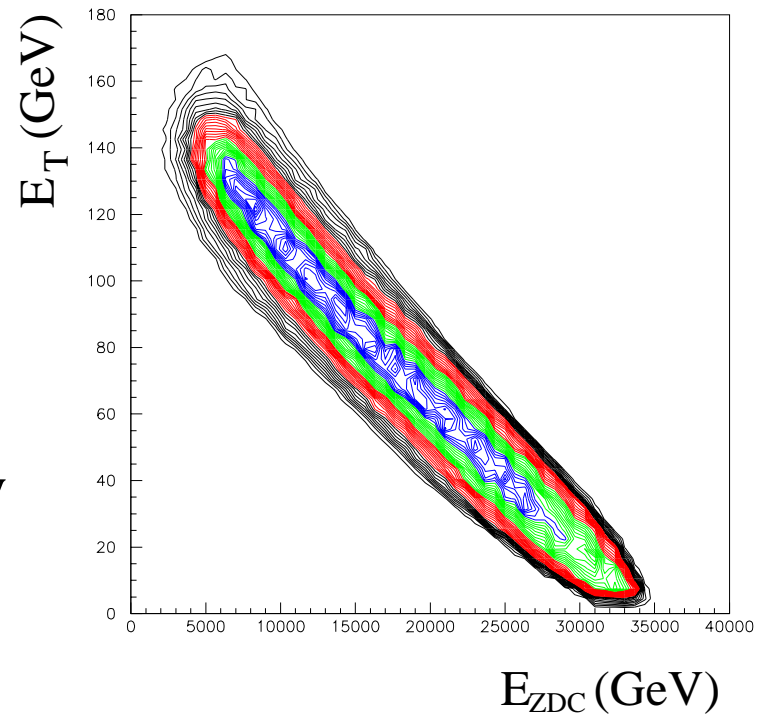


# Collision Geometry



Impact parameter is not directly measurable, so it must be inferred by measuring correlated observables.

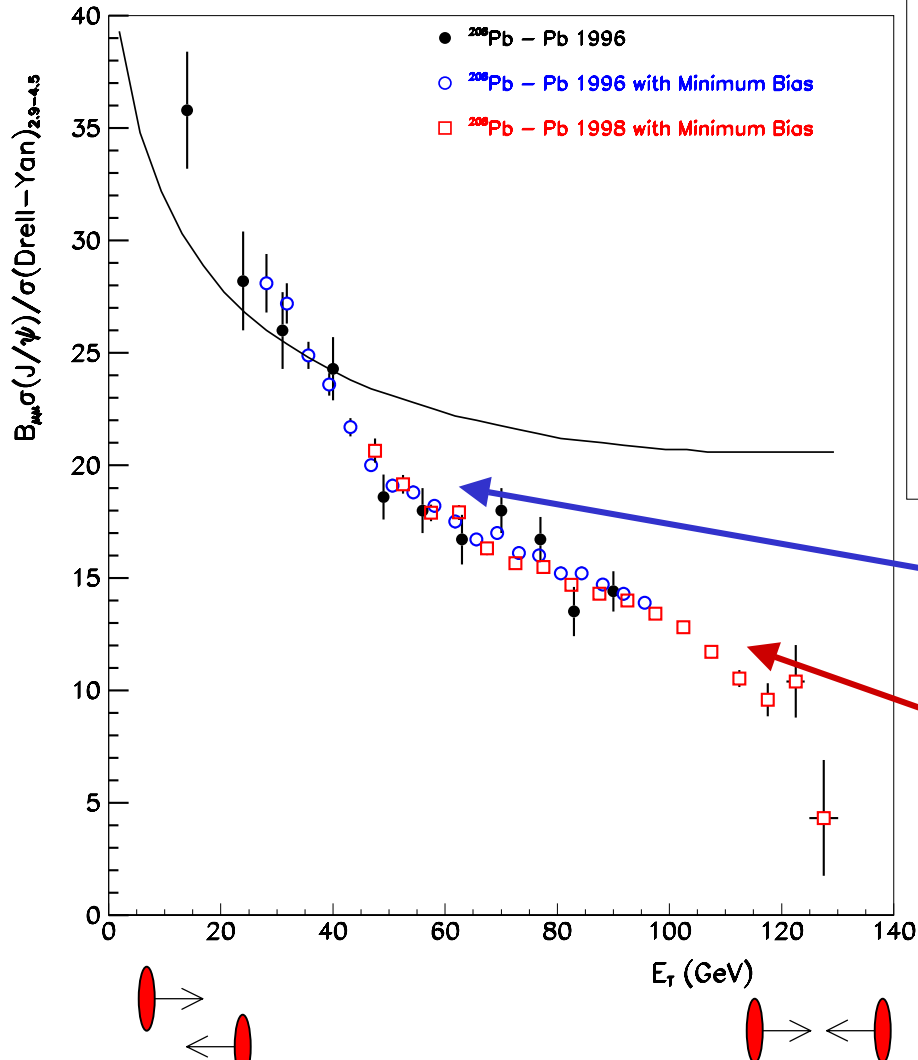
NA50





# Sequential Suppression

NA50 at the CERN-SPS



“Strong evidence for the formation of a transient quark-gluon phase without color confinement is provided by the observed suppression of the charmonium states  $J/\psi$ ,  $\chi_c$ , and  $\psi'$ .”

Maurice Jacob and Ulrich Heinz

Discontinuity due to  $\chi_c$  melting

Drop due to  $J/\psi$  melting

Using Drell-Yan as control

# NA50 Web Page

## NA50 Publications

### Evidence for deconfinement of quarks and gluons

from the  $J/\psi$  suppression pattern  
measured in Pb-Pb collisions at the CERN-SPS

*Physics Letters B*, in print; CERN-EP-2000-013 [PS file](#)

#### Dimuon and charm production in nucleus-nucleus collisions at the CERN-SPS

*Euro. Phys. J. C*, in print; CERN-EP-2000-012 [PS file](#)

#### Low mass dimuon production in proton and ion induced interactions at the SPS

*European Physics Journal C13* (2000) 69; CERN-EP / 99-112-Rev [PS file](#)

#### Observation of a threshold effect in the anomalous $J/\psi$ suppression

*Physics Letters B450* (1999) 456; CERN-EP / 99-13 [PS file](#)

#### Observation of Fission in Pb-Pb Interactions at 158 A GeV

*Physical Review C59* (1999) 876 [Text \(PS file\)](#) and [Figures \(PS file\)](#)

#### $J/\psi$ , $\psi'$ and Drell-Yan production in pp and pd interactions at 450 GeV/c (NA51 Collaboration)

*Physics Letters B438* (1998) 35 [PS file](#)

#### The quartz-fiber Zero-Degree Calorimeter for the NA50 experiment at CERN SPS

*Nuclear Instruments and Methods in Physics Research A411* (1998) 1

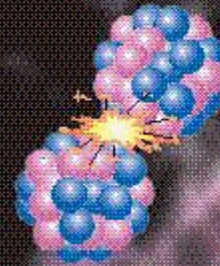
#### Anomalous $J/\psi$ suppression in Pb-Pb interactions at 158 GeV/c per nucleon

*Physics Letters B410* (1997) 337 [PS file](#)

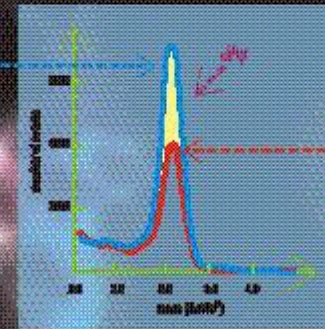
**“We must conclude that the  $J/\psi$  suppression pattern observed in our data provides significant evidence for the deconfinement of quarks and gluons.”**

NA50: CERN-EP-2000-013, Accepted Phys. Lett. B

# results of the experiment NA50



**Peripheral lead-lead collisions:**  
The  $J/\psi$  production corresponds to the low curve

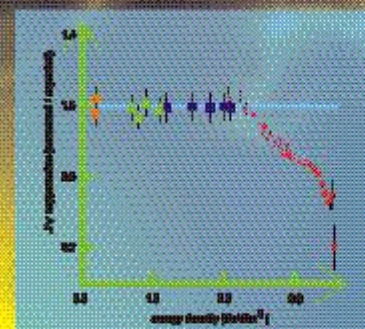
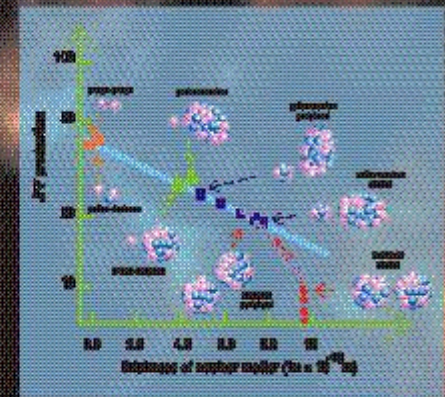


**Central lead-lead collisions:**  
The  $J/\psi$  production is a factor of 2 lower (red curve) than the corresponding one observed in peripheral collisions

The nuclear modification factor can be done with various model of different sizes

The important variable is the path length of the produced  $J/\psi$  in the surrounding nuclear matter. The  $J/\psi$  can be absorbed during its travel and the apparent suppression of the  $J/\psi$  production has nothing to do with a possible quark-gluon plasma formation

From p-p collisions to central Pb-Pb collisions, the experimental  $J/\psi$  production shows an exponential absorption law due to the interaction of the  $J/\psi$  with the medium of the colliding nuclei

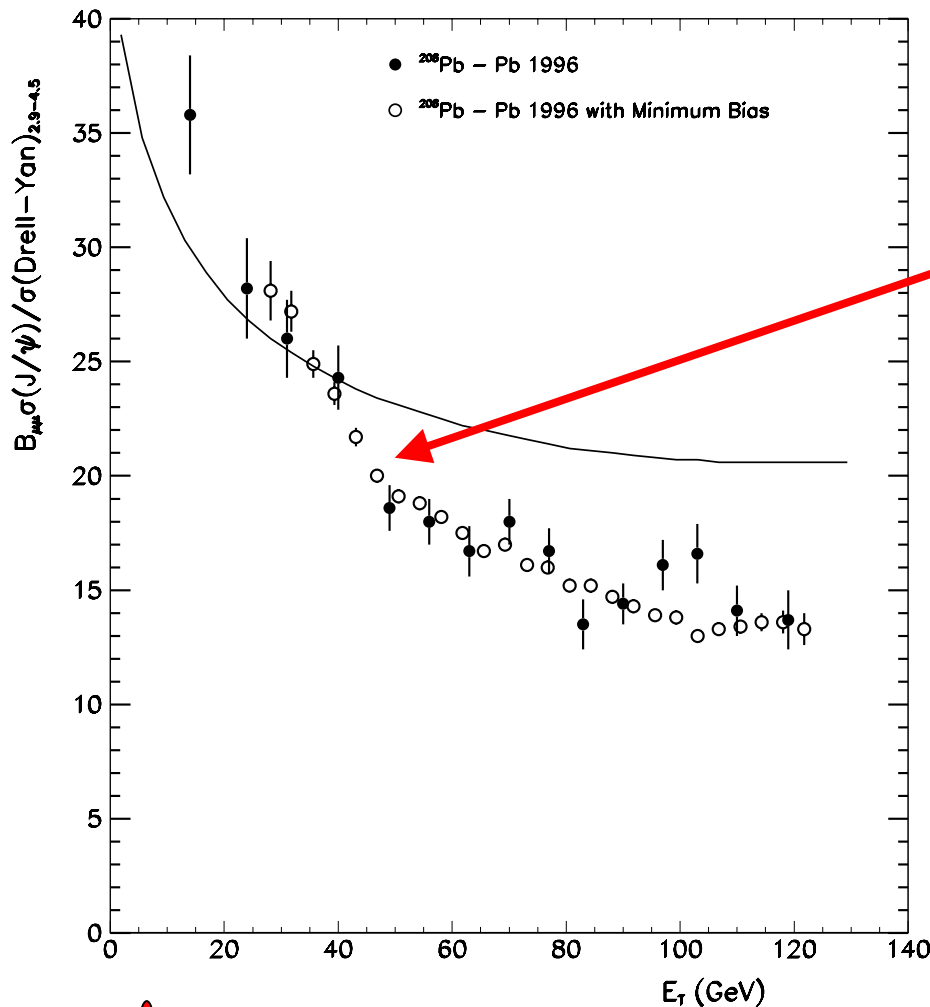


For Pb-Pb collisions, a new phenomenon occurs: the simple exponential absorption law is no longer valid

The relevant variable is the energy density reached in the interaction

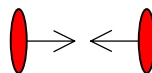
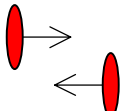
**quark - gluon plasma !!!**

# Non-Monotonic Derivatives



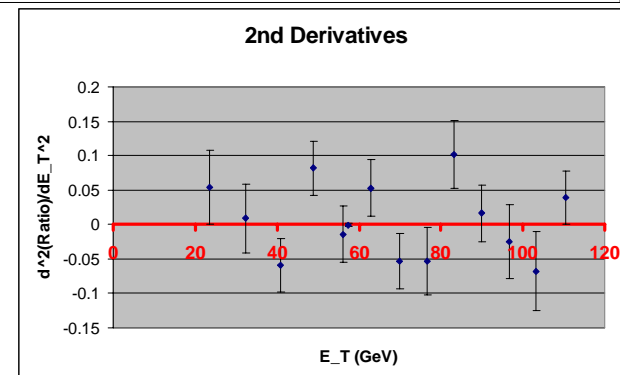
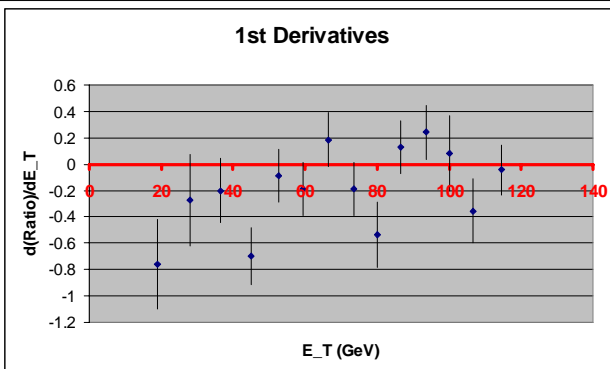
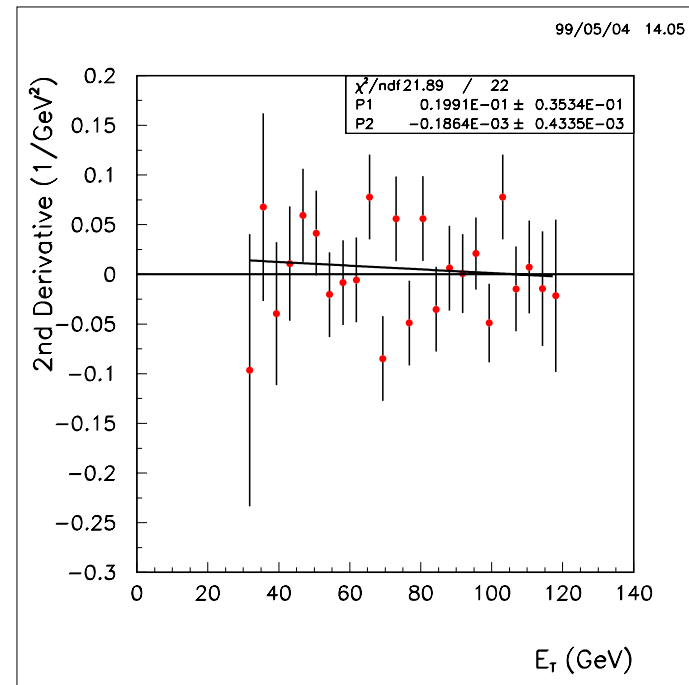
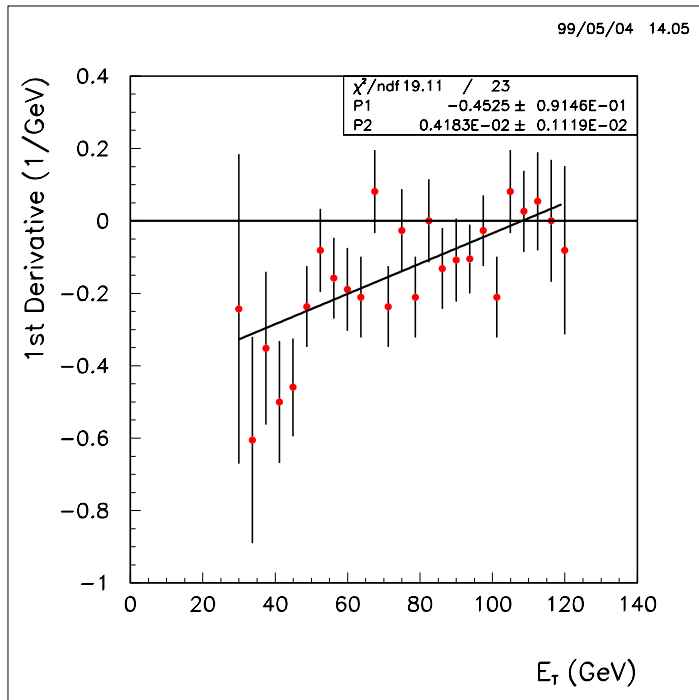
“A clear onset of the anomaly is observed. It excludes models based on hadronic scenarios since only smooth behavior with monotonic derivatives can be inferred from such calculations”

Phys. Lett. B 450, 456 (1999).



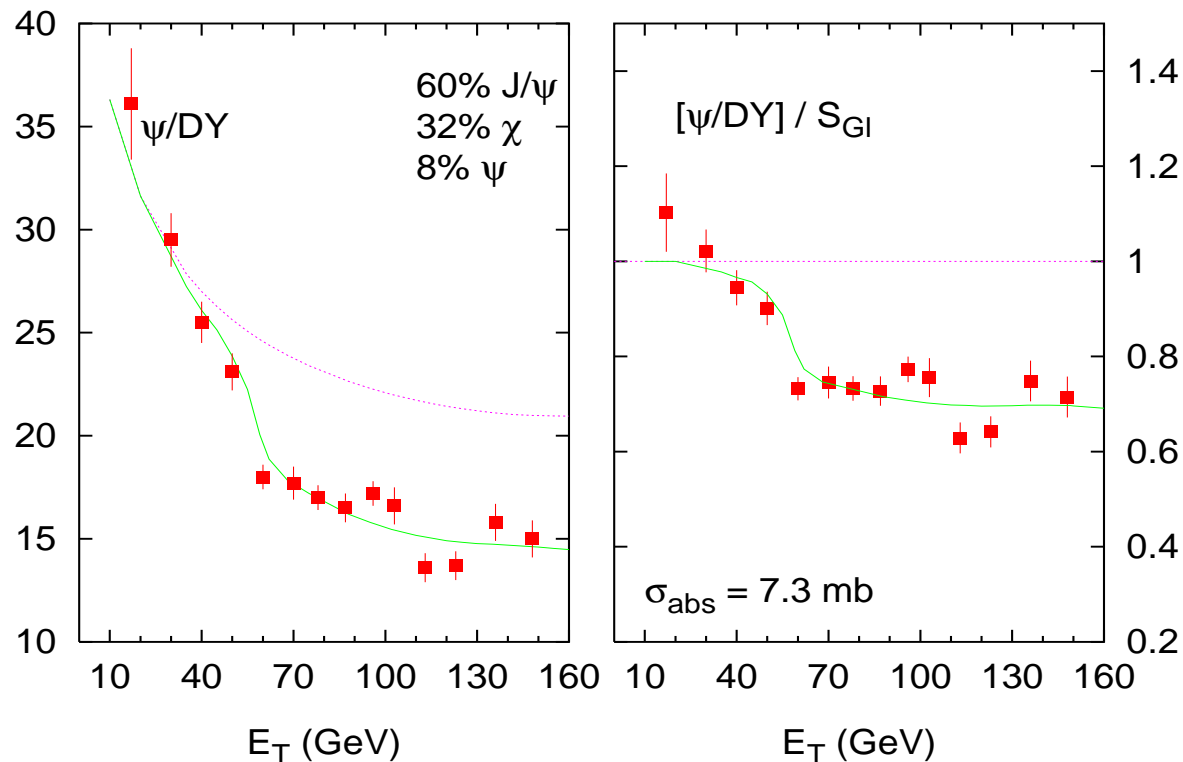


# Mathematical Definitions



# Plasma Theory

Invoking a model of bubble nucleation, one is able to reproduce the suppression. This implies a relatively strong 1st order phase transition.



# “Hadronic” Models

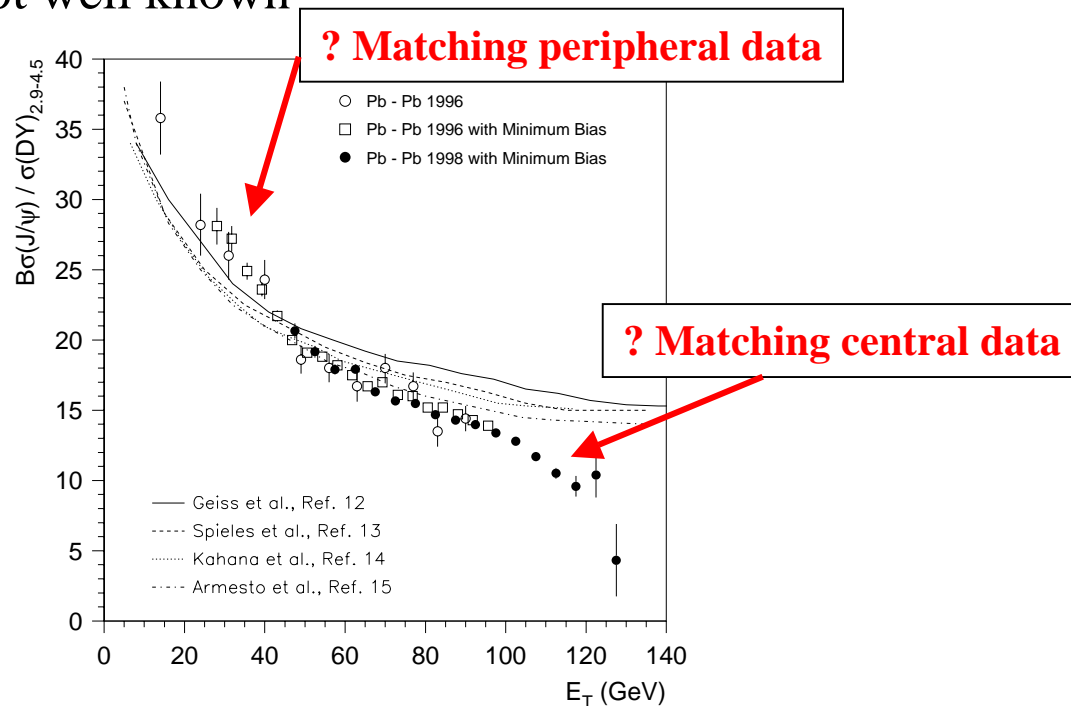
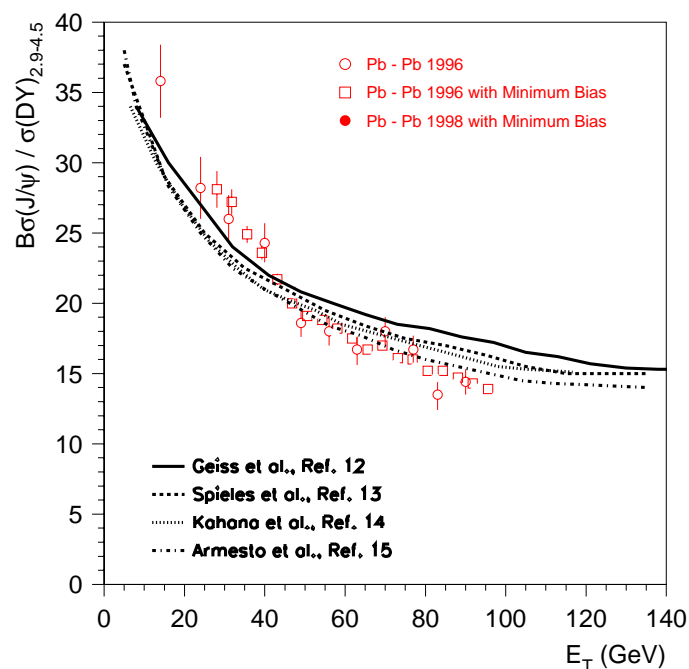
There is expected “hadronic” suppression of  $J/\psi$  due to:

- pre-resonance absorption on target and projectile nucleons

\* see next talk by E866/NuSea for more details

- final state interactions with  $\pi$ ,  $\rho$ , etc.

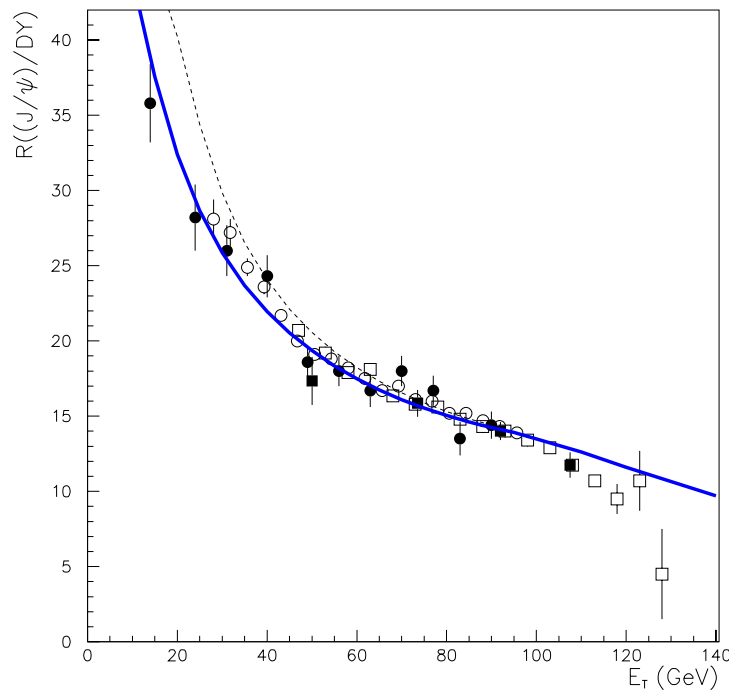
\* cross sections not well known



? Consistent with p+A, S+U and p+A (\*Fermilab)

# More “Hadronic” Models

Different modeling of  $E_T$  production and detector response may play a significant role.

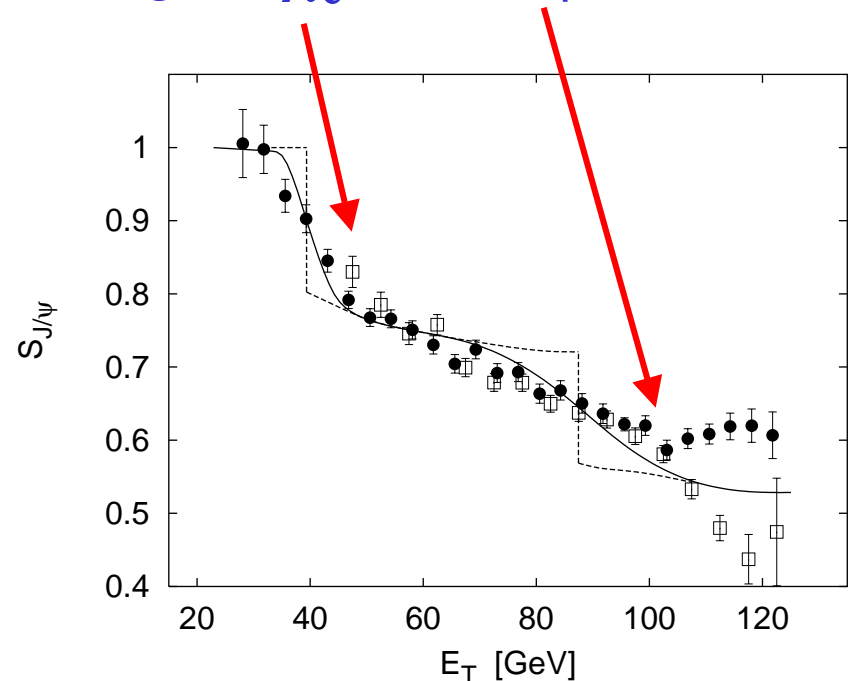
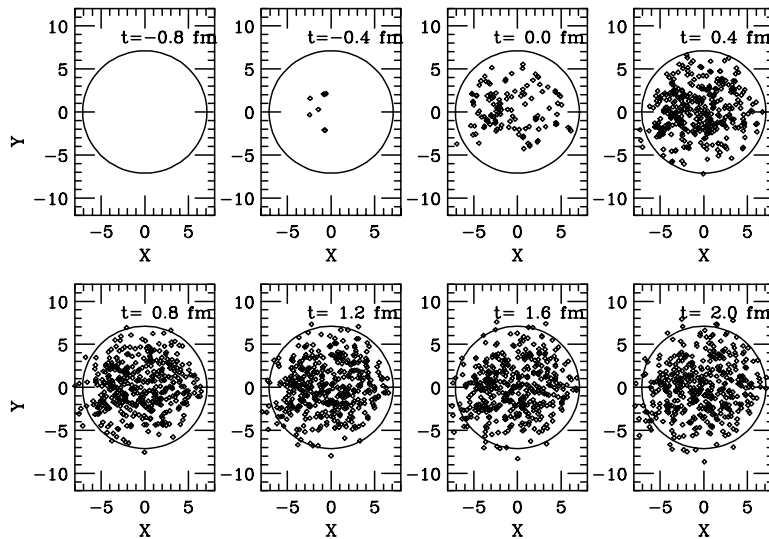


(Capella, Ferreiro and Kaidolov, hep-ph/0002300)



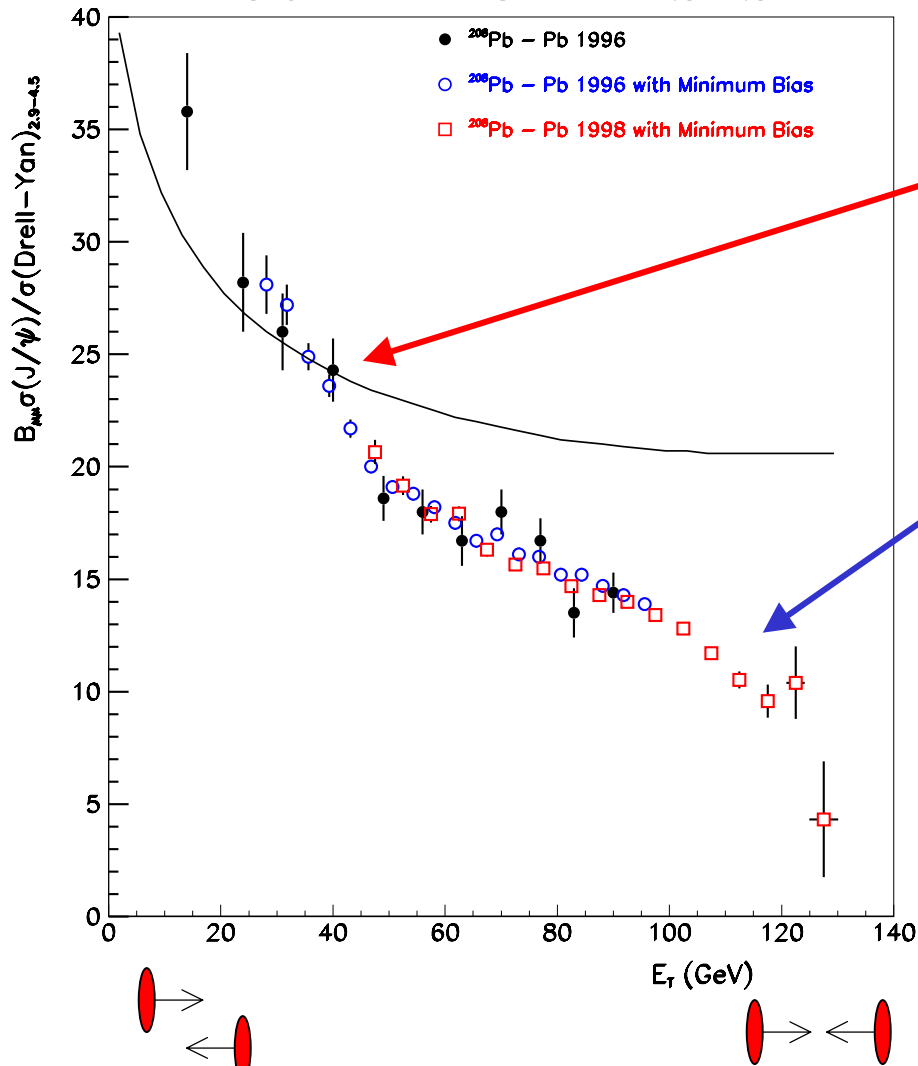
# Percolation

Percolation model of H. Satz looks at localized parton densities and above a critical density assumes a strong 1st order phase transition (similar to bubble production). Sequential melting of  $\chi_c$  and  $J/\psi$  seen.



# Thick Target Correction

## NA50 at the CERN-SPS



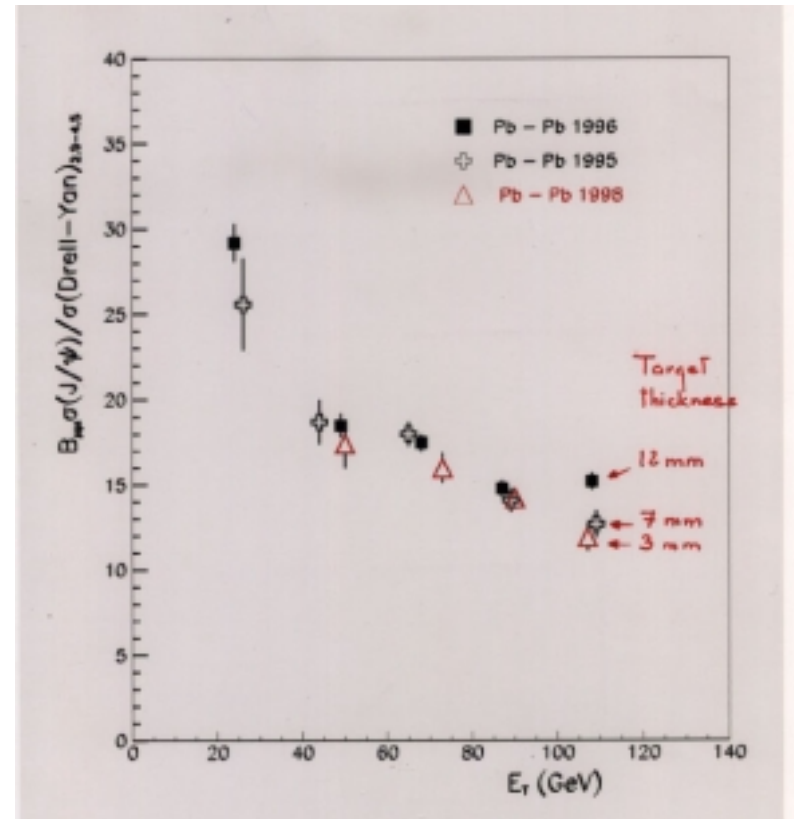
1998 data not included on plot:

With a 7% target in 1998 there was a “high contamination of Pb-air interactions, [but is] found to be negligible for  $E_T > 40$  GeV. Since the main goal of the 1998 run is to study the suppression pattern in central Pb-Pb collisions, we have limited the analysis to  $E_T > 40$  GeV.”

1996 data not included on plot:

“With a 30% target, it is conceivable that a spectator fragment from a first peripheral collision reinteracts downstream, resulting in measured values of  $E_T$  and  $E_{ZDC}$  typical of central collisions.”

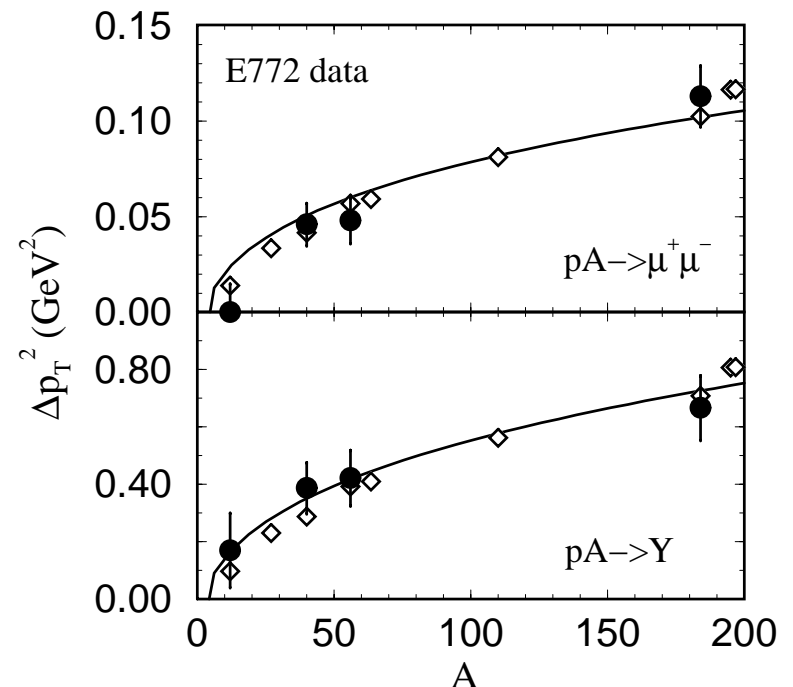
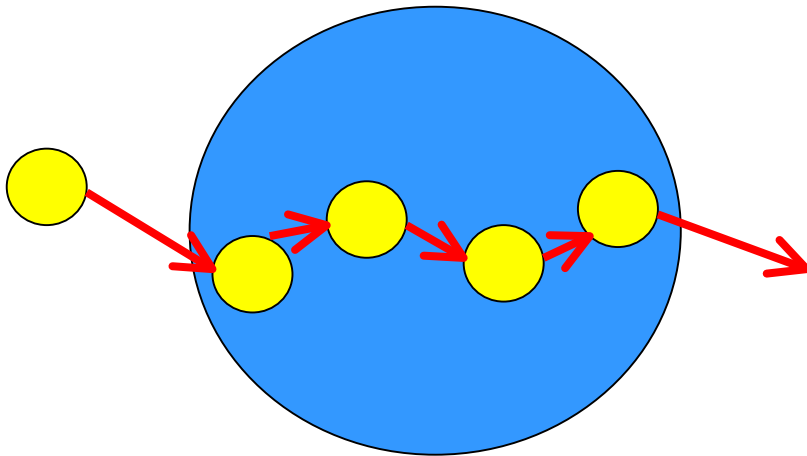
# More Targets



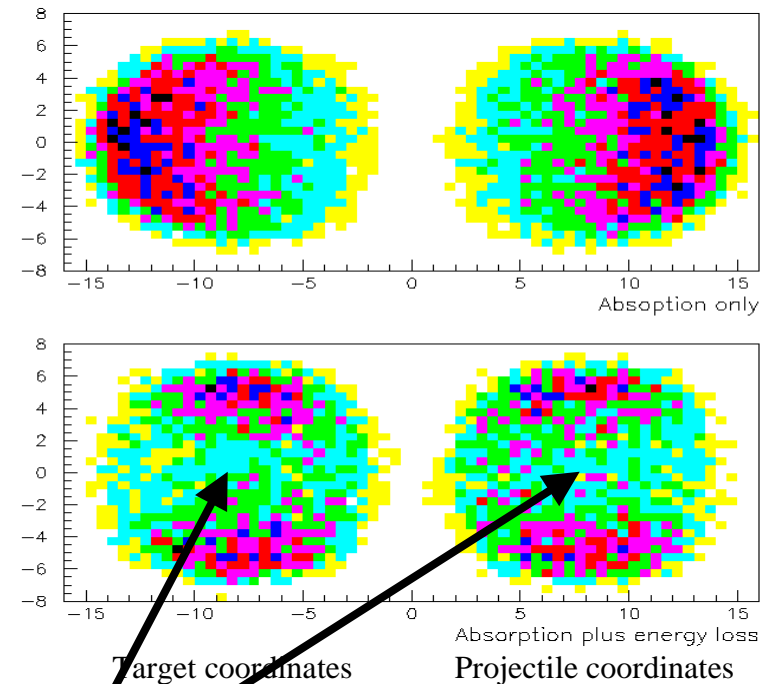
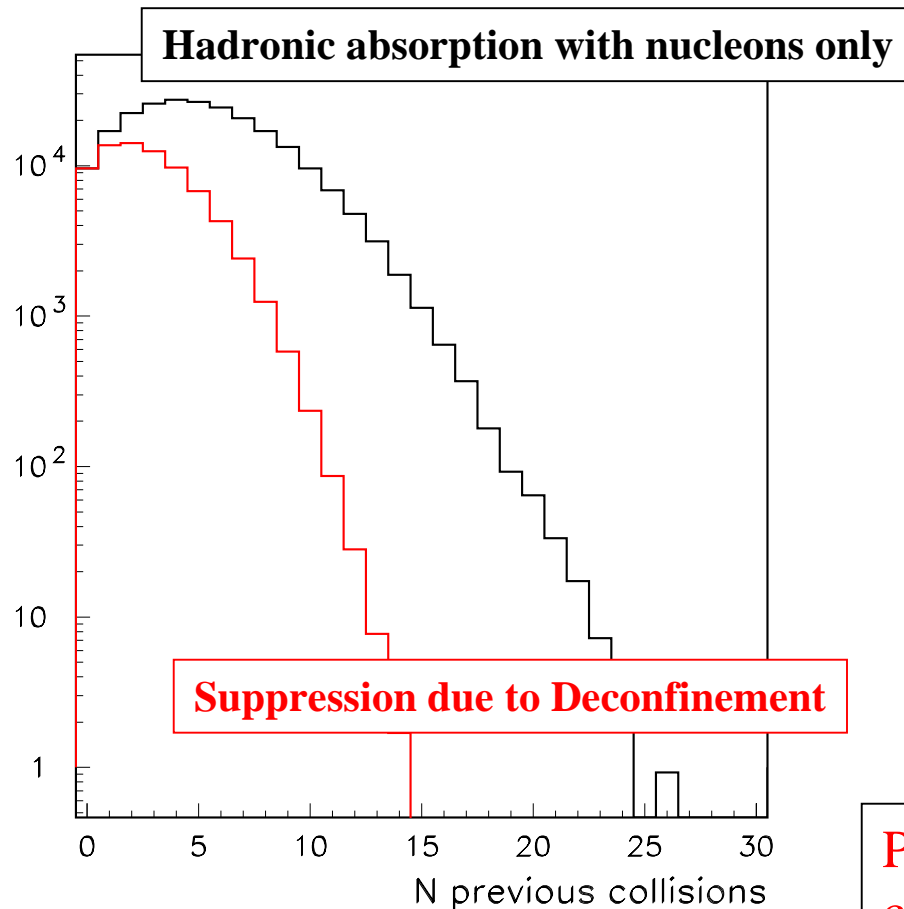
# Transverse Momentum

Prior collisions broaden the transverse momentum spectrum (“Cronin effect”)

$$\langle p_t^2 \rangle_N = \langle p_t^2 \rangle_{pp} + (N-1) \Delta p_t^2$$

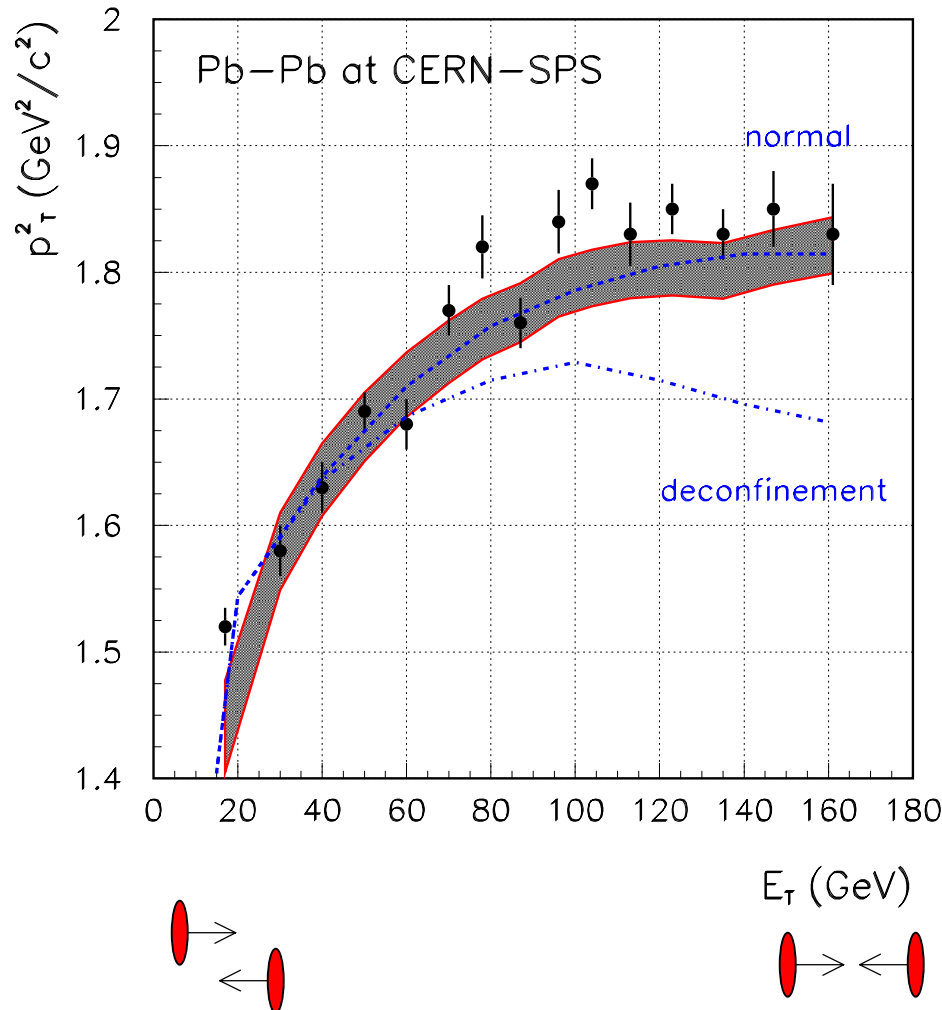


# Number of Previous Collisions



Plasma breaks up  $J/\psi$  formed at the core of the collision, which are the ones most likely to have the largest number of previous collisions ( $N$ )

# Data and Predictions



There is much more information in the full  $p_T$  spectra, which has not been shown.

Early predictions had suppression at low  $p_T$ , since these objects spend more time in the plasma.

Opposite effect of that shown here.

# Energy Density

Lattice QCD predicts a phase transition at  $\epsilon_c \sim 0.6$  GeV/fm<sup>3</sup> or  $T_c \sim 170$  MeV.

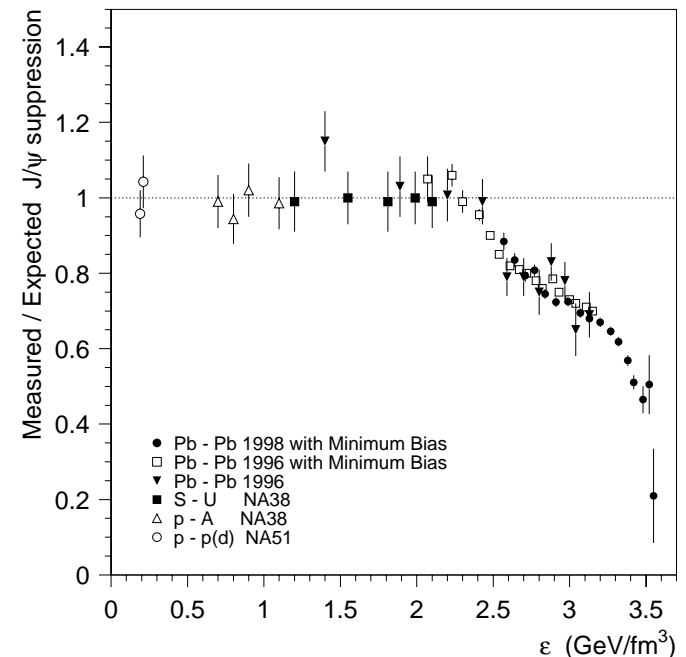
- S + S collisions reach  $\epsilon \sim 1$  GeV/fm<sup>3</sup>
- Plasma formation seen via strangeness enhancement

Above  $\epsilon \sim 2$  GeV/fm<sup>3</sup> the  $\chi_c$  state melts

- Percolation model indicates strong 1st order transition

Above  $\epsilon \sim 3$  GeV/fm<sup>3</sup> the J/ $\psi$  state melts

- Most central Pb + Pb collisions reach  $\epsilon \sim 3.5$  GeV/fm<sup>3</sup> or  $T \sim 240$  MeV



\* These transition densities are not predictions.

# Estimating Energy Density

“*Highly Relativistic Nucleus-Nucleus Collisions: The Central Rapidity Region*”,  
J.D. Bjorken, Phys. Rev. D27, 140 (1983).

Assumes ~ 1-d hydrodynamic expansion and then boost invariance.

(A) From measured  $E_T$  and Bjorken's formula:

$$E_{\frac{\tau_0}{2}} = \underbrace{\frac{1}{\pi R_{ms}^2}}_{\substack{\text{overlap} \\ \text{area}}} \underbrace{\frac{1}{2\tau_0} \frac{dE_T}{dy}}_{\substack{\text{length of} \\ \text{fireball at } \tau_0}} \quad \left( \text{assumes } \tau = y \right)$$

$\uparrow$  63 fm<sup>2</sup>       $\uparrow$  2 fm       $\uparrow$  400 GeV (NA49, PRL 75 (95) 3816)  
 40% more in 'very central' colls.

$\rightarrow$   $E_{\frac{\tau_0}{2}}^{n-p} (1 \text{ fm}^2) = 3.2 \pm 0.3 \text{ GeV/fm}^3$

Press release argues for 3-d hydrodynamic expansion, and  $\tau$  is unknown within a factor of 4.

Energy density is large! However, comparing this to a theoretical value from lattice QCD with no net baryon density is difficult.



## Summary

1. A new state of matter, at about  $20 \times \epsilon_{\text{Nucl. Matter}}$ , has been created.

It behaves collectively, leading to a gigantic explosion of the collision fireball ( $\tau_{\perp}^{\text{exp}} > 0.5 \text{ s}$ ).

→ "The LITTLE BANG"

2. This state exhibits features which cannot be understood in terms of conventional hadronic interactions:  $\approx$  chemical equilibrium, strangeness enhancement,  $J/\psi$  suppression

They require strong interactions, with large inelastic cross sections, in a state of  $\epsilon \approx 1 \text{ GeV/fm}^3$ , and they are consistent with expectations from a plasma of deconfined quarks and gluons.

3. The hadron abundances appear to provide a snapshot of the predicted quark-hadron transition at  $T_{\text{had}} \approx 170 \text{ MeV}$ .

→ "primordial hadrosynthesis"

There is no question that these exciting observations constitute a quantum jump in our understanding of matter at extremely high temperatures and densities and testify to the great success of the CERN heavy ion program.

"new state of matter"

energy density  $\sim 20 \times \epsilon_{\text{nucl. matter}}$

chemical equilibrium

strangeness enhancement

$J/\psi$  suppression

Great success of the CERN  
heavy ion program !

In spite of the above, the evidence is not enough to prove, beyond reasonable doubt, the creation of "Quark-gluon Plasma!"

### Missing Pieces:

#### Theory:

- A complete, consistent, dynamical theory of HICs which includes quark-gluon d.o.f. and the quark-hadron transition and explains all data. (May be easier at RHIC/LHC than at SPS.)
- Elimination of other "non-conventional" early stage mechanisms (color ropes, baryon junctions, ...)  $\rightarrow$  pp, pA, AA'

SPS

#### Experiment:

- Energy threshold for quark deconfinement? SPS
- System size threshold for collective behavior and chemical/thermal equilibration? SPS
- Open vs. hidden charm (normalisation of  $T_k$ ) SPS  
RHIC/LHC
- Measurement of "GGP structure functions" by direct electromagnetic radiation RHIC/LHC
- Probing the GGP with hard probes (jet quenching, jet acoplanarity, open beauty,  $X, X', \dots$ ) RHIC/LHC

The higher energies of RHIC and LHC are needed to complete the picture and provide a full characterization of the Quark-gluon Plasma.

# Theorists and Experimentalists

NA50 tries to have statement with no theory  
Strangeness without theory

excitation function via geometry and energy ---- geometry is  
harder

# Conclusions

- The CERN program has
  - Created nuclear matter at unprecedented densities
  - Explored its properties in unprecedented detail
  - Provided unprecedented challenges to the theoretical community
- The RHIC heavy ion community is ready to begin experiments with a set of detectors designed for the first dedicated heavy ion collider
  - The variety, energy, uniqueness, promise and challenge of this program exceeds even that of the very impressive CERN era.

# Thank you

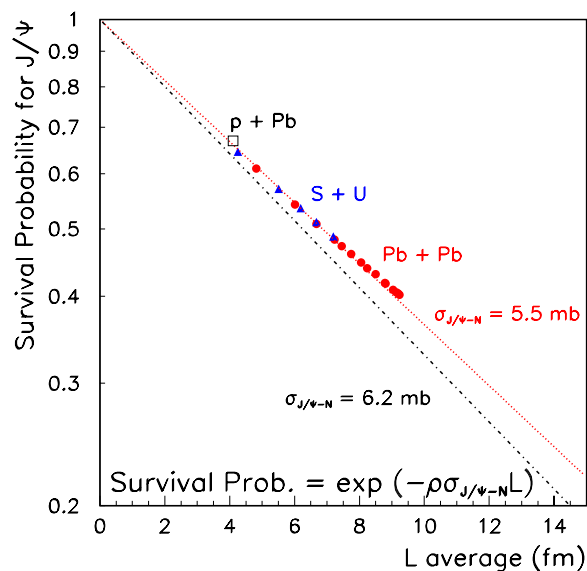
Thanks to Peter Steinberg, Mickey Chiu, Marzia Rosati, Mike Bennett, Bill Zajc and many more.....

I hope this exciting physics stimulates more discussion and more work (since this is a workshop).

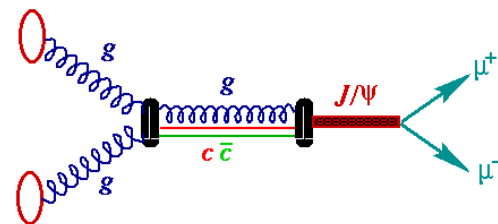
- Look into strangeness enhancement at all energies
- Look into multi-strange baryon models
- Look into percolation models and co-mover models
- Look into thick target corrections
- Look into predictions for transverse momentum spectra
- .....
- A long list should keep us busy this week

# “L” Parameter

The NA50 extracted cross section is systematically low.  
The cross section is approximately  $\sigma = 7\text{-}8 \text{ mb}$ .



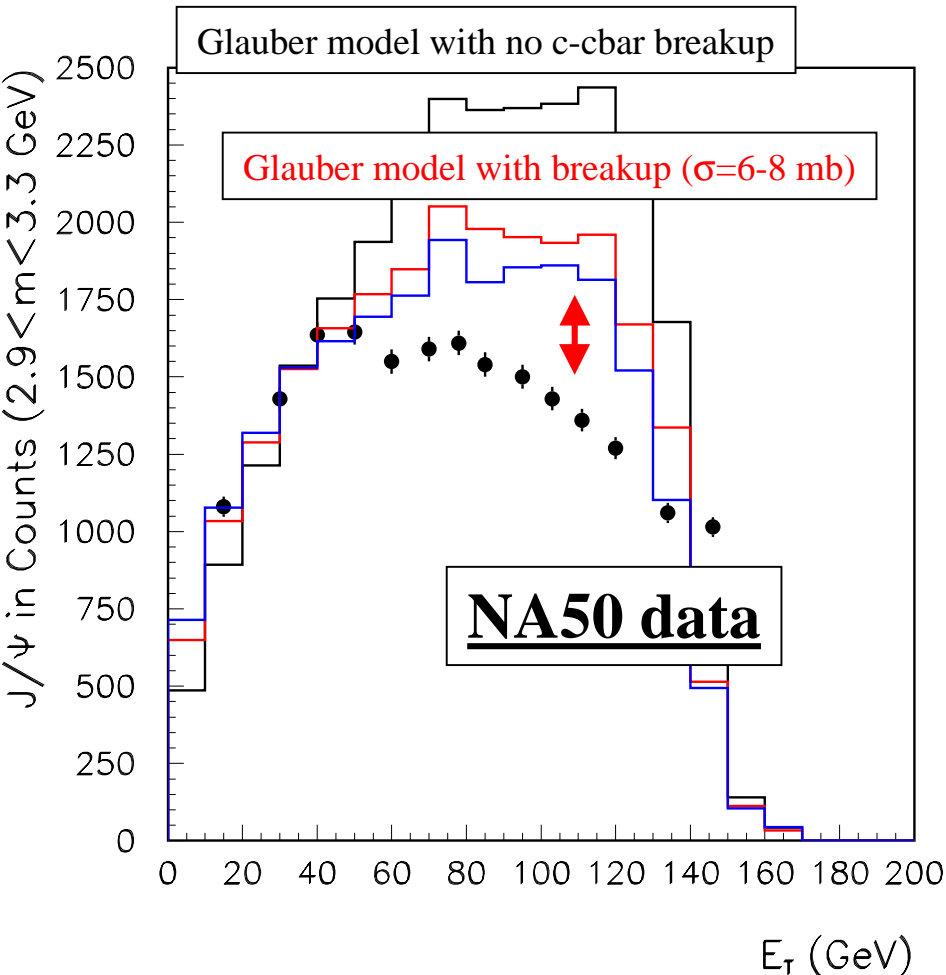
Average path (L) is not a good variable for precision studies.



One expects  $\sigma = 2\text{-}3 \text{ mb}$  in the color-singlet  $c\text{-}\bar{c}$  state.

There is evidence from  $p\text{-}\bar{p}$  and  $p\text{-}A$  for color-octet state.

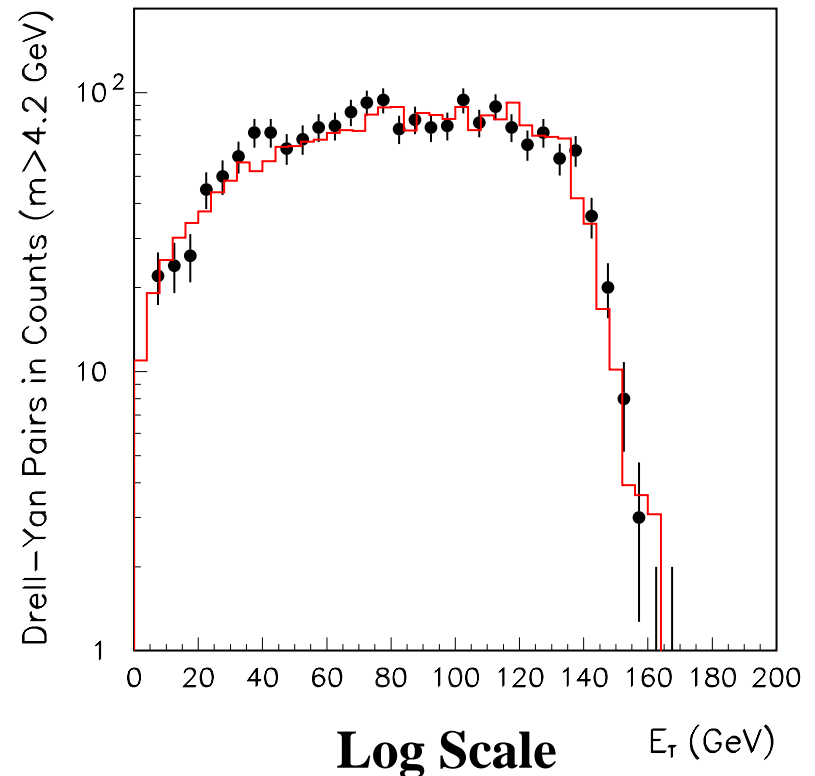
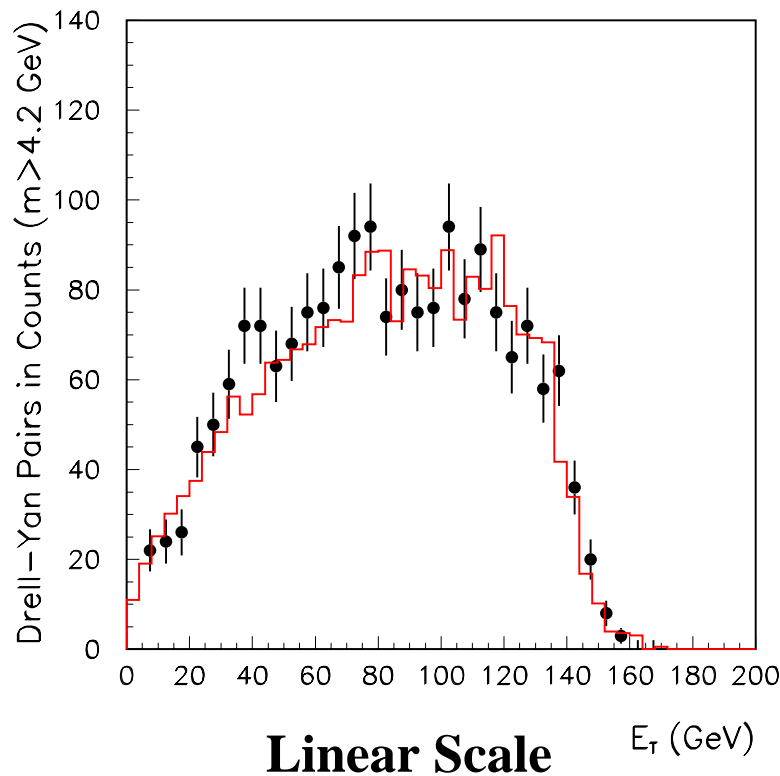
# J/ψ Suppression



1. **Formation of Quark-Gluon Plasma and dissociation of the  $J/\psi$ !**
2. Interactions with hadronic co-movers ( $\pi, \rho, \dots$ )
3. Initial State Energy Loss reducing  $J/\psi$  production
4. Other Ideas....

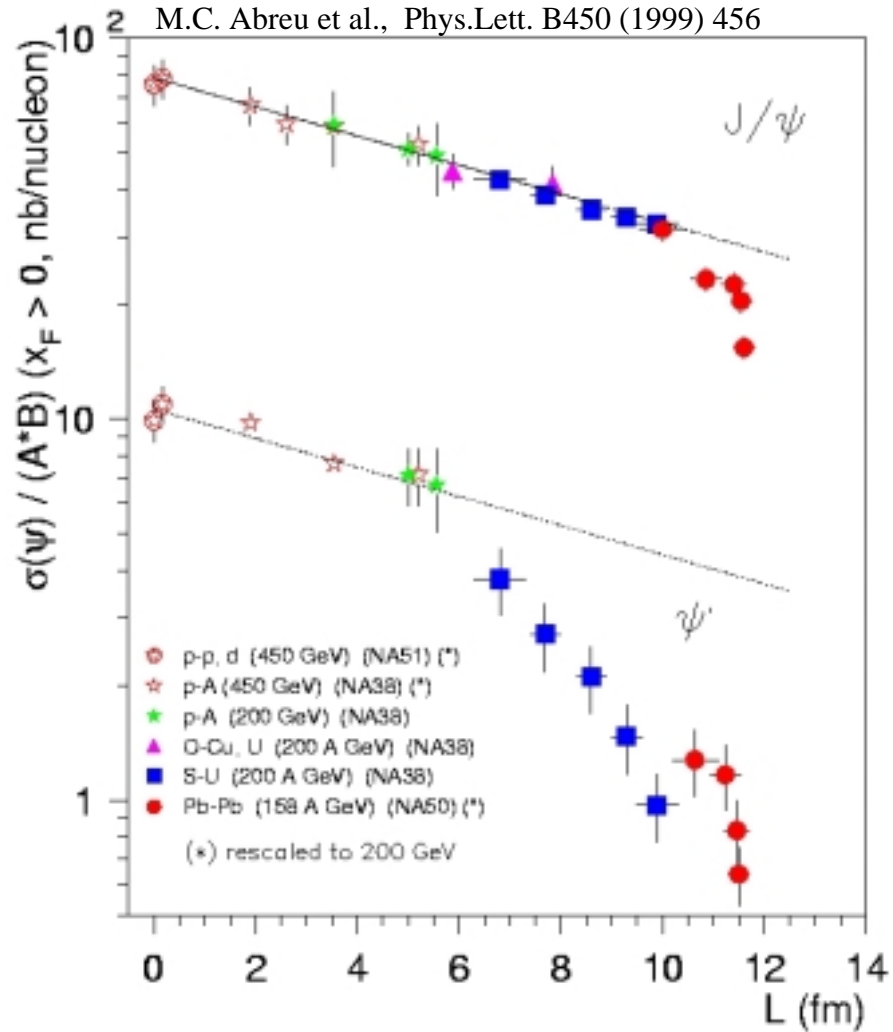
# Drell-Yan

**Glauber Model** calculation gives an excellent description of NA50 (**1996**) Drell-Yan transverse energy spectra. Includes fluctuations in  $E_T$  production and calorimeter resolution.





M.C. Abreu et al., Phys.Lett. B450 (1999) 456





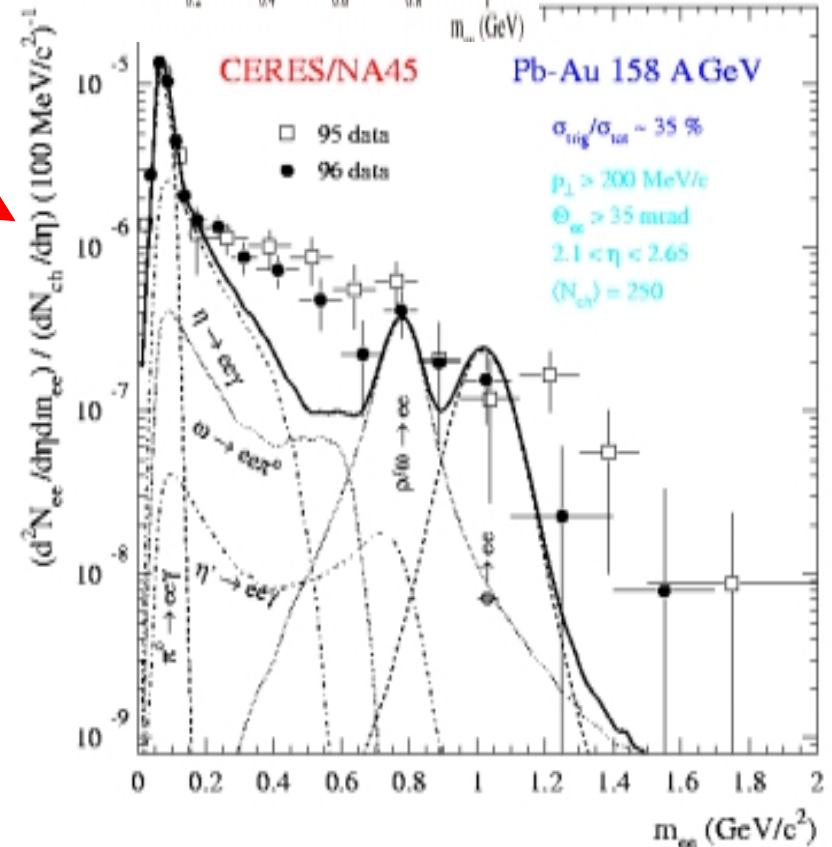
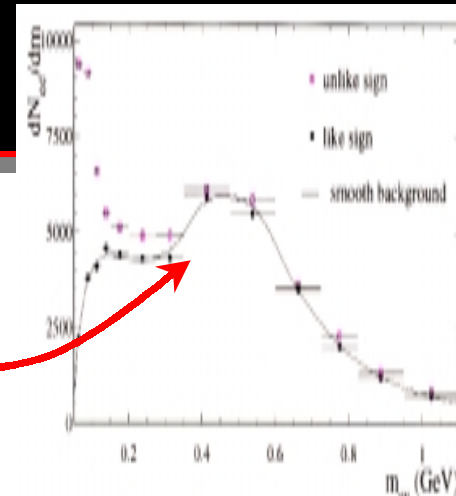
	BNL AGS	CERN SPS	BNL RHIC
Temperature (MeV)	90-95	100-120	ALL
Expansion Velocity	~0.5	~0.55	ALL
Energy Density (GeV/fm <sup>3</sup> )	1-2	2-3	ALL
Strangeness	Increased	Increased	ALL
Multiply Strange Hyperons	Hint (Only)	Increased (CQM?)	STAR, PHOBOS(?)
Electron Pairs	No	Medium Modifications(?)	PHENIX
J/Ψ		Suppressed	PHENIX, (STAR)
Direct Photons		Limit	PHENIX
Hard Scattering		Hint	PHENIX, STAR
Charm		Hint	PHENIX
Beauty		No	PHENIX(?)

- S
- e channel

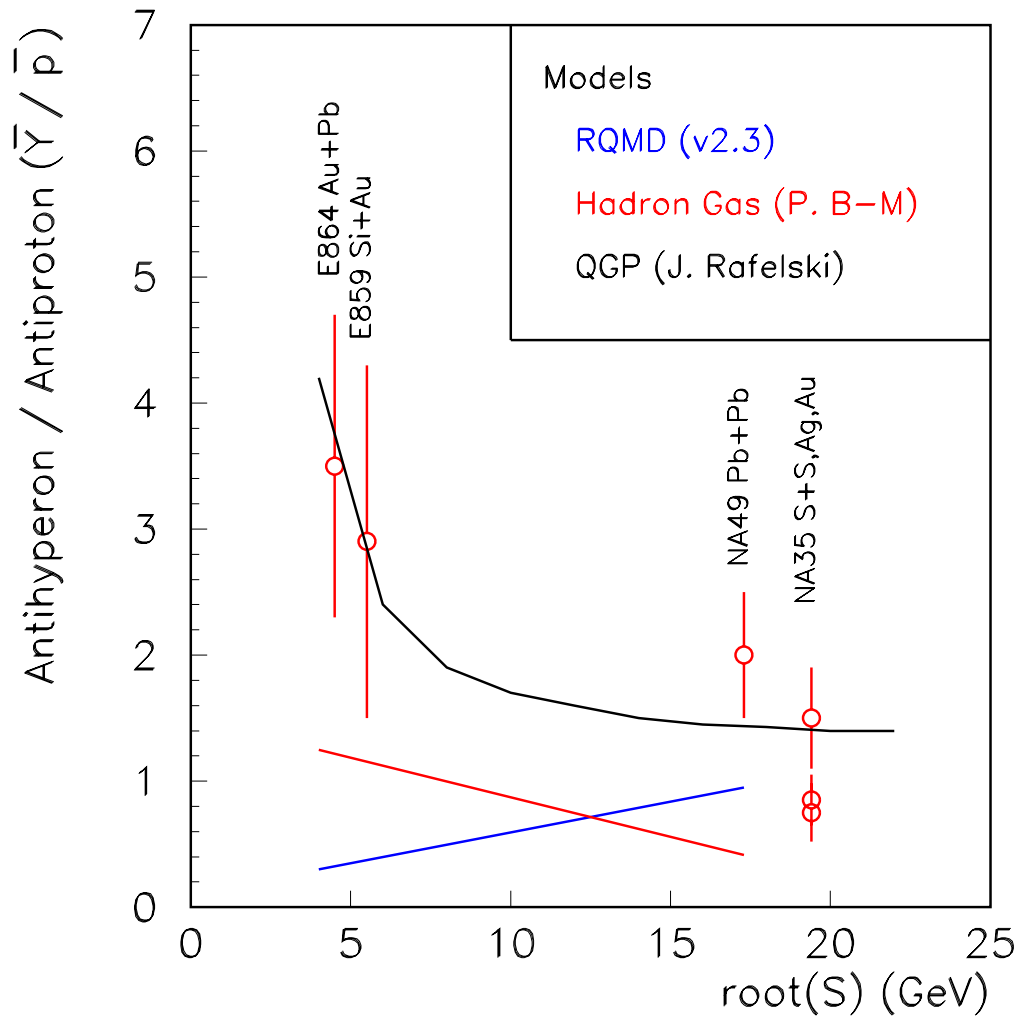
- After heroic efforts to
  - Suppress Dalitz pairs
  - Suppress conversions
  - Understand background

- Then:
  - Form  $M(e^+e^-)$  spectrum
  - Divide by charged yield
  - Compare to known sources

- Excess seen for
  - $0.3 \text{ GeV} < M(e^+e^-) < 0.7 \text{ GeV}$
  - from
  - $\pi\pi$  annihilation?
  - $\rho$  collision-broadening?



# Antilambda Yields



# Chemical Equilibrium

